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DEVELOPMENT OF DEPLOYABLE

SOLAR ARRAYS

Contract NAS 5-3987

REPORT NO. 64B119

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RYAN

AERONAUTICAL COMPANY

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1.0 INTRODUCTION

This is the Summary Report of studies and investigations by Ryan Aeronautical Company for the National Aeronautics and Space Administration, Goddard Space Flight Center. The studies were performed under Contract NAS 5-3987. The work accomplished concerns the Study Phase (Phase I) of a program to develop a Deployable Solar Array to be used for solar energy conversion by photovoltaic means to provide electrical power for an orbiting, spin-stabilized spacecraft.

Seventeen concepts were selected for study and evaluation. Each concept was carried through a design layout stage. Preliminary analytical studies were conducted of structural and electrical characteristics. Dynamic and thermal considerations were evaluated to determine effects of such constraints on representative concepts. Certain design verification tests were performed to demonstrate feasibility of design features and applicability of materials and processes.

The report summarizes the investigations; presents substantiating data generated, and submits Ryan's recommendations for a design which appears most suitable for the intended application.

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2.0 SUMMARY

Design and test investigations selected a segmented beam concept which fulfills Goddard's design parameters. Further design work has produced engineering drawings, which present detailed solutions to the problems of construction, packaging, deployment and rigidization. A working 1/2-scale model has been constructed to demonstrate the concept. Further investigation indicates recommended variations of the basic concept, which uses available volume inside the shroud to a greater advantage than the present envelope, and could be better adapted for larger arrays.

Author

RYAN 64B119

3.0 DESIGN DISCUSSION

The objective of this program is to develop a semi-rigid or flexible solar array concept for a non-oriented, spin stabilized spacecraft which exhibits improved packaging capabilities and which will provide an efficient method of deployment and rigidizing of the solar array. Throughout the evaluation studies, concept selections and detail design, the paramount concern was to establish a configuration that was mechanically, electrically, and functionally reliable, as well as economically producible. While special consideration could be given to delicate or special features of the design, the entire approach should include state-of-the-art fabrication and ease of handling without special equipment or especially trained personnel. Following this philosophy Ryan evaluated each concept for fabrication, handling, storage, operation and environmental acceptability. These studies have produced a selection of solar array configurations which fulfill the program objectives.

3.1 DESIGN CRITERIA

The pertinent data used for the design of the deployable solar array are:

CRITERION	REQUIREMENTS
1. Spacecraft description	Non-oriented (spin-stabilized)
2. General characteristics and function of array	a. Maximum utilization of volume between spacecraft and shroud. b. Provides deployment and rigidization in space, compatible with spin-stabilized spacecraft. c. Compatible with present solar cell mounting techniques. d. Provides large area and lightweight solar array.
3. Type of construction	Semi-rigid or flexible
4. Packaged configuration	All elements of assembled array to be within an envelope of: Width = 13 inches Length = 25 inches Depth = 4 inches
5. Deployed configuration	Array shall be approximately 1 foot wide by 8 feet long.
6. Solar cell mounting provisions	a. On both sides of the 1 foot by 8 foot array providing a minimum of

CRITERION	REQUIREMENTS
	8 square feet usable solar cell area per side.
	b. Substrate surfaces shall be compatible with RTV-40, or equivalent, for attaching cells.
7. Deployment mechanism	Type of actuation: May be mechanical, chemical, pneumatic, other equivalents, or a combination of methods.
8. Deployment conditions	a. Static: Capable of maintaining rigid configuration in the earth's gravitational field when the longitudinal axis of the array is directed towards the earth's gravitational field.
	b. In-flight:
	(1) Capable of positive deployment. Centrifugal force may be used as a positive deployment media. The mounting plane of the array shall be 20 inches from the centerline of rotation of the spacecraft.
	(2) The deployment rate shall not exceed .5 ft/sec.
	(3) Maintain dimensional integrity while spinning on spacecraft body at: Initial rate (before deployment) of 80-160 rpm. Final rate (after deployment) of 20-40 rpm.

CRITERION	REQUIREMENTS
	c. Capable of reliable operation in hard vacuum of space.
9. Weight	a. Not to exceed 12 pounds.
	b. Includes substrate, solar cells (and associated wiring, inter-connectors, 6-mil filter glass) and deployment mechanism.
10. Environment	
a. Materials	Non-magnetic materials
(1) Humidity	(1) Up to 95% relative humidity at 30° C for 24 hours.
(2) Radiation	(2) Ultraviolet and hard particles (as experienced in space). Micro meteorite damage shall not be considered.
(3) Hard vacuum	(3) 1 to 5 years without excessive deterioration.
b. Extended array	Capable of withstanding thermal cycling test at 10^{-7} torr pressure from -70° C to +70° C for 1000 cycles at nominal rate of 2 hours per cycle.
c. Packaged array	Capable of:
(1) Temperature-storage	(1) 100 days at temperatures varying from -20° C to +60° C.
(2) Vibration	(2) Capable of withstanding shock, vibration and accelerations might be experienced during launch. (See GSFC "Guidelines", Pages 2 and 3, Paragraphs 7-a., b. and c. for tests and conditions.)
d. Other	Structure shall be capable of meeting above without degrading solar cell performance.

3.2 DESIGN PHILOSOPHY

The choice of the design (presented here as the best approach to the design parameters) involved a constant re-evaluation of requirements and solutions as various concepts were explored by layouts, model construction, testing and discussion.

While it was possible to package the required substrate simply as folded semi-rigid hinged panels, this approach was not pursued because the main purpose of the investigation was improvement in state-of-the-art in building and deploying flexible substrates.

Many attempts were made to incorporate a method of substrate deployment without using radial g loads while performing a 1 g demonstration. The conclusion was inevitably that a redundant system would be required which would have no use in space, since the panel is deployed while the spacecraft is rotating. Because package weight was a critical problem, redundant systems were discarded. Using centrifugal force to deploy the substrate became the most logical approach.

The problem of panel deployment is one of restraint and rate control during a relatively high spin condition of the spacecraft. The major problem was to provide adequate support to the deploying substrate at all times, and to control the rate in order to minimize the induced side loads.

Configuration studies were conducted to establish a design which was capable of supporting a substrate weighing approximately 8 pounds horizontally in a 1 g field at time of deployment. A full size mock-up was constructed and loaded to simulate solar cell weight. This produced an array which exceeded the allowable packaging envelope and weight. For the concept chosen, static deployment was demonstrated in a 1 g field by suspending the package horizontally and allowing gravity loads to deploy the substrate downward. A 1/2-scale model will be demonstrated in this manner.

The requirement that the panel be rigidized in space, was to insure that the panel would remain flat if centrifugal loads disappeared or if unexpected side loads or torsional loads were encountered. A reasonable beam stiffness will overcome such problems and will remain within the weight and space envelope. A beam of minimum height should be provided to eliminate as much shadow as possible.

The fabrication, inspection, handling and replacement of damaged solar cells of large arrays are costly and time consuming. To minimize this, a modular concept was established as a primary objective for the design of the array.

A non-sun oriented craft would require the panels to rotate in relation to the deployment plane. Provisions to accomplish the angular rotation of the deployed array will be included which do not require movement of the entire package.

The design selected should be capable of use on larger arrays, but parameters will change as area grows. For example, the problem of beam shadow can be solved completely by moving the beams to the dark side of the panel, since a large array would very probably be sun-oriented. At the same time, this spacecraft would probably not be spin stabilized, and panel deployment would require an added system. This system would replace the retention system now needed to oppose the high centrifugal loads. Therefore, while the general concept is valid, specific design changes would be required, depending on the spacecraft configuration.

3.3 CONCEPT STUDIES AND EVALUATIONS

Seventeen concepts were investigated. Eight basic concepts include various actuation, support and rigidizing schemes. A general appraisal of these eight concepts follows. For a detailed analysis of all seventeen concepts, refer to the references noted.

3.3.1 Segmented Beam Concept (Ref. Fig. 1, Concept 1)

This concept employs a combination of semi-rigid and flexible substrate sections supported by two beams attached directly to the sides of the substrate, thus providing direct support along the entire length. The beam is divided into segments at the bends and provided with a tensioning cable for rigidizing.

The substrate and beams are wrapped on a lightweight core for packaging and are deployed by centrifugal force. Control of the deployment rate is accomplished by cables and straps payed out by an electric motor. The method of rigidizing a substrate has proven to be one of the major design problems. This concept incorporates an approach which solves this problem simply and reliably, and is accomplished automatically by a negator spring system which applies tension to a cable threaded through the beam caps. For a description of operating sequence refer to Paragraphs 3.4.2.1 thru 3.4.2.3. The electrical connections to a fixed substrate end, as opposed to a moving or rotating part, are greatly simplified and reliability is improved since no sliding or rotating connections are required. Other advantages are: In addition to flexibility and adaptability to other envelopes, the semi-rigid portions of the array are adaptable to cell lay-up using large 2x2 cm cells. Additional length may be provided by adding extra folds.

A disadvantage of this concept may be a beam shadow on one side of the panel. Beam heights, however, can be very low (approximately 1/2 inch), thus minimizing the effect. Blocking and zener diodes may also be used to eliminate affected cells.

3.3.2 Hinged Folding Panel (Ref. Fig. 1, Concepts #3, 5, 7, 9)

These concepts include various sizes and configurations of semi-rigid and rigid panels in the design envelope. Deployment of these panels is by various devices such as lazy tong beams, torsion spring hinges, telescoping tubes and torsion spring loaded folding struts.

Construction is semi-rigid, and with the exception of the telescoping tubes, are fairly simple to rigidize by snap locks or tension cables. These designs lend themselves to modular build-up, and are reliable due to simple mechanical linkages used during deployment. Packaging would require damping mats or bumpers to reduce vibration and cell damage. Cell mounting provisions are excellent, since minimum bending exists between cells. The problem of vibration deflection would increase if these designs were scaled up to large arrays.

While there are certain merits of these concepts, the flexible aspect of Goddard's request is left unexplored, and the state-of-the-art in flexible arrays is not advanced.

3.3.3 Roll-out Spiral Wrapped Single Reel (Ref. Fig. 1 Concept #11, 17)

The general approach of rolling a long blanket on a single drum appears to be a very good solution, since it eliminates the present problem of making long panels sufficiently rigid for dynamic loading during the boost phase. A rolled blanket of cells, separated by a protective matting, would be ideal for the high vibration of launch. The relatively simple method of controlling substrate deployment rate by an escape mechanism on the mounting reel is also advantageous. The electrical connection of a rotating end, while not as desirable as a stationary end connection, still does not present as great a design and reliability problem as that of connecting to a free traveling end, common to the roll-out loop. The method of rigidizing could employ many systems, ranging from the segmented beam type to a roll formed beam as shown on referenced concepts.

After many attempts to apply a rigidizing system to a rolled substrate, it was found that, within the design envelope, the substrate could not be rigidized by attaching a member to it throughout its entire length. The substrate, at best, would have to be supported at several points which would slide over an extending member.

The other approach would be to attach to one end of the array and keep the substrate taut by the extending supports.

Systems of rigidizing, using foamed supports are not presented here because of their questionable reliability and their inability to provide for partial deployment and retraction. In this concept, it is necessary to use narrow 1x2 cells aligned with the cells on the opposite face, since the entire substrate must be rolled.

3.3.4 Roll-out, Spirally Wrapped Dual Reels (Ref. Fig. 1 Concept #14)

This design approach is a variation of the single reel method of Paragraph 3.3.3. Cells are mounted on one side of a flexible substrate, and each end is rolled onto a separate roller. The array is extended by centrifugal force, and rate-controlled by an electric motor. Rigidizing is accomplished by extending telescoping struts, attached to a cross-brace at the center of the substrate. Two separate sections of substrate would eliminate the need for aligning cells for flexibility, and also would possibly eliminate the protective mat, since cells would be separated by the substrate material.

While the concept retains good dynamic packaging and ease of deployment rate control, it has the disadvantage of the single reel which requires 1x2 cells over the entire length. There is also difficulty in rigidizing, and the less desirable electrical connection of the rotating part. Additional weight occurs because of the extra length of substrate material; electrical connection to an additional rotating end is required; the resulting curvature of the substrate loaded by centrifugal force and supported at each end, and the center is a disadvantage, and the distance separating the two rollers increases the problem of rotating the substrate after deployment without affecting the entire package.

3.3.5 Roll-out, Loop Wound, Dual Reels (Ref. Fig. 1 Concepts #2, 6, 8, 10, 15, 16)

This package consists of two rollers covered by a flexible substrate, with cells on both sides. The substrate is looped around the two rollers as illustrated, and successive layers are separated by protective matting.

Deployment primarily uses centrifugal force, and initial extension is by various means that would also rigidize the substrate after deployment.

The construction for this approach does have the advantage of being adaptable to the package, and demonstrates flexibility, but the concept appears to be one of the less desirable, since when packaged, major portions of the substrate are unsupported, and this, in turn, requires external damping. Another disadvantage is that the inboard end of the substrate travels in a path from one parallel roller to the other, as the substrate deploys. As the panel reaches full extension, a reliable electrical connection must be made to this moving end, which also must resist a continuous centrifugal force on the extended panel. In addition, 1x2 cells are required, and all cells must be alined with cells on the opposite side of the substrate to allow the substrate to flex. The problem of connecting the substrate to a rigid member also exists, and the only solution is to connect at a few points along the sides with sliding connectors, or to rely on one connection across an end member to keep the substrate taut.

3.3.6 Wrapped Drum Concept (Ref. Fig. 1 Concept #4)

This may be described as a combination of flexible and semi-rigid substrate material, with cells attached to both faces. The subtrate material is wrapped on an oblong drum with protective matting being used to separate cell surfaces. The substrate is extended by moving the drum outboard of the packaged position, and rotating the drum to allow centrifugal force to pull the array outward. Telescoping tubes are extended to support a member across the outboard end of the substrate. This provides tension in the substrate and stiffens it. No connections are possible at the sides, because of the varying angle created by the array when deploying from a rotating oblong drum.

Use of an oblong drum is an excellent method of packaging the array, since support is provided for the entire length of the substrate. Vibration problems would thus be minimized. Use of the drum as a mounting surface for cells on the two flat surfaces, would reduce the required length of the flexible substrate and also provide separate modules of cells. This feature of the design is an alternate to the use of the combination flexible (sections) and semi-rigid substrate for the entire eight feet.

Control of deployment rate is accomplished by electric motor and reduction gear. Positive rotation of the drum is provided by this arrangement with or without the centrifugal load, and the motor runs under varying load conditions but with a constant deployment rate.

Other advantages of this concept are good dynamic characteristics in the packaged condition; adaptability to the use of 2x2 cells over major area; ease of deployment control and adaptability to modularizing.

Some problems to overcome include providing rigidity, in addition to that given by end attachment. Electrical connection of rotating drum is a disadvantage. Other problems include minimizing weight of extension mechanism and the drum to remain within package weight; and synchronizing extension of struts to prevent binding and substrate distortion.

3.3.7 Folded Substrate (Ref. Fig. 1 Concept #12)

In this configuration, telescoping channels provide a package into which a flexible substrate, with cells on both sides, is folded in fire hose fashion. Rotating the entire package 90°, then extending the channels allows centrifugal force to pull the array from its package. Negator springs are used to extend the channels. Synchronization and rate control are accomplished by a cable leading from the channels to an electric motor. This same cable and motor control the movement of the entire package through the first 90°.

To enable this configuration to survive the vibration environment and the acceleration loads of take-off, shaped separator cushions are inserted at each fold. These separators would be cast into space as the array unfolds.

This concept, along with others using deep beam sections, was investigated in an effort to provide horizontal support in a 1 g field. When this proved unfeasible, as discussed in Paragraph 3.2, any remaining advantages were not able to offset the great disadvantage of the long shadow cast by a deep beam. In addition, the many spacers required to separate and to cushion the array for packaging result in a cumbersome system.

3.3.8 Telescoping Panels (Ref. Fig. 1 Concept #13)

Semi-rigid panels with cells on one side are attached to channel legs and progressively smaller sections are telescoped inside one another to form the packaged configuration. The package is stowed parallel to the satellite centerline and rotates out 90° before centrifugal force extends the array. Deployment rate control is accomplished by an electric motor and cables.

This concept was also evaluated in order to provide horizontal stiffness in a 1 g field (Ref. Para. 3.2), while eliminating the shadow effect of the beams by mounting the substrates on the outer faces of the beam. This approach would require stiffeners from opposite channels to give the separate sections sufficient stiffness for handling fabrication cell lay-up and operation. Strips of the substrate must be free of cells to provide for vibration damper strips to be attached to the substrate surface. Protective mats cannot be used, since the surfaces must slide in relation to one another. The last section would have braces to pick up the dampening pad loads from the remaining structure.

The advantages of a simple extension method, good rigidity, adaptability to modular design, and good provision for cell mounting appears to warrant further investigation, but a serious weight problem would arise when attempting to make the modules sufficiently stiff to resist handling and vibration loads. As with the hinged folding panels, this method is not as feasible as flexible substrates.

3.3.9 Summary of Dynamic Considerations

In all cases of flexible substrates, 3/8 inch clearance is required laterally between frame and the nearest array element in the stored configuration, unless padding is used in the clearance space. Between adjacent layers of stored elements of the array, 3/4 inch clearance is needed, unless padding is used in the clearance space. If the adjacent layers in the stored configuration are attached at the edges at a few spots so that the layers move together at the edges, then only 3/8 inch clearance is needed. (The centers of the panels move out-of-phase with one another, but not as far as if the edges were unconstrained.) The amount of padding required is minimal. The main principle is to fill the voids between frame and layer, and between layers, so that normal-to-panel motion is prevented when in the stored configuration.

The environmental condition that dictates the clearance requirement (or padding) is the response at the low end of the white noise band (11.5 g rms 20-2K cps is specified). The response at the low end of the sine wave test is almost as critical.

Another matter that applies to all of the deployable arrays is the spin condition, which is quite critical. One may visualize a radial g field that varies from about 7 g's stored, to about 42 g's fully deployed. The centrifugal force at the root in the fully deployed condition is about 450 pounds. In all configurations, some kind of a rate control device is required to limit the radial velocities during deployment to small values. Otherwise, the array would fly out (deployment time would be about .1 sec.), with excess kinetic energy at the end of the deployment sequence, (on the order of 10,000 lb/in.), and with large side forces required to maintain the array in a radial position rather than a tangential one. These side forces are proportional to the radial velocity, and if a rate control device limits the radial velocities to small values, then the side forces (as well as the end K.E.) can be made small.

Any of the configurations that raise the center of gravity vertically (along the vehicle spin axis) during outward deployment require further investigation. In these cases, there are imbalancing forces that can, if deployment velocities are even moderate, set up severe resonances and whipping at multiples of the spin frequency, similar to helicoper blades during vertical gusts. This matter should be considered in detail in any design concept selected. This problem can be reduced to insignificance by reducing deployment rates to .5 feet per second, or less.

3.3.10 Summary of Structural Considerations

Structural problems are reduced considerably with a concept which remains packaged and well dampened during the launch phase of flight. Present solar panel designs which are rigid and supported at a minimum number of points to reduce spacecraft superstructure (and in most cases because of the lack of a place to attach to superstructure) are severely loaded by a combination of booster engine vibration and steady state launch acceleration g forces. These forces and vibrations, if coupled with critical fundamental frequencies, can deflect the solar panel to a magnitude which will affect electrical operation after injection of the craft into space.

It is possible to eliminate the launch problem in a fully packaged solar panel by the use of cushioning media and similar devices, but substrate loads are not yet eliminated due to deployment of a solar panel mounted on a spin-stabilized craft. Problems which need further investigation of this condition were discussed in Paragraph 3.3.9.

Rigidizing the packaged solar cell substrate after deployment is one area of concern which must be investigated with great care if the resulting structure is to be efficient with minimum weight. It must be remembered that an addition of an outside mass to the substrate results in an increase in substrate weight and cross-section, with a loss of the primary objective, namely, large arrays for less weight per unit area than the present state-of-the art provides.

Handling during assembly and while under demonstration in an earth environment will impose greater loading conditions in some directions than could be experienced during launch and an intended spacecraft mission. Careful consideration must be given, in these cases, if severe weight penalties are not to be imposed on the resulting package.

3.3.11 Summary of Thermal Considerations

The basic design requirement for any space system is that of optimum efficiency with minimum weight. Solar cells, in general, are delicate units and must be properly protected from extreme environments during launch, deployment and orbit. The thermal environment of the cell must be maintained within definite temperature limits if efficiency is expected.

A solar panel is usually constructed by mounting a cell by some form of adhesive to a rigid substrate. This substrate is used to provide strength to the panel, but in so doing tends to cause a heat sink, temperature gradients, and conductance of heat from the parent structure. If a very thin fibrous substrate with good thermal properties is used, a large saving in panel weight is possible. If the substrate is only a few thousands of an inch thick, the temperature difference between cells, considering they are placed back to back, would be very small. Under thermal cycling, the heat sink effect of the thin fibrous substrate would be radically reduced over one constructed of aluminum, and should give better temperature stabilization between solar cells. One of the principal advantages would be reduction of the heat flux from the spacecraft to the panels by conduction. Since the rate of heat flow by conduction is a function of the cross sectional area of the substrate, a substrate consisting of a few thousands of an inch in thickness should eliminate nearly all of the heat flow to the cells.

Thin substrates consisting of fibrous material appear to be an area where further investigation should be done. Such a substrate could be designed to give high strength in a given direction, along with desirable thermal properties.

3.3.12 Concept Evaluation and Reliability Considerations

Since any discussion of the multitude of factors involved in this subject is likely to become complex, and many important points about each design are lost, a collection of these data have been arranged in chart form and presented in Figure 1 as a detailed summary of the 17 concepts presented. A schematic drawing is included on the chart for definition and quick reference of the general concept.

3.3.13 Selected Concept Justification

A review of the foregoing evaluations indicates that some advantages and disadvantages are quite outstanding; others are very subtle or possibly just a matter of opinion. It is therefore appropriate at this time to review briefly the criteria that Ryan feels are the most important in selecting and separating the feasible concepts from unfeasible and, finally, in selecting the concept that will best fulfill the particular design parameters.

These questions must be answered: First, can the concept be manufactured, handled and tested without a high scrap rate, and without many special devices and procedures? Secondly, is the concept capable of taking high vibration and acceleration loads of the boost phase without damage to the solar cells or structure? Third, will the array deploy at a controlled rate and survive the high centrifugal loading imposed by the spinning craft? Fourth, will the structure be stiffened adequately to allow complete removal of centrifugal loading in the event of a spin direction reversal, and will the array be rigid enough to take side loads or torsional loads after rigidizing? Fifth, is the concept adaptable to modular approaches; to other packaging envelopes and larger arrays? Finally, do all aspects of the design fit together to present a reliable working unit?

Certainly, other criteria such as thermal characteristics, material properties, etc. (Ref. Section 3.1) are considered, but do not tend greatly at this phase of the design to separate and distinguish between basic concepts.

The segmented beam configuration Concept #1, was selected as the choice of the best over-all solution. Design was carried to the point of presenting a preliminary set of drawings which define the details and assembly of a full size prototype unit. (Ref. Fig. 3 thru 8.) A review of this design discloses no areas that are impractical for manufacture, handling, or testing. The materials used are common, and manufacturing techniques are state-of-the-art. The major differentiating factors are the handling of an array after cell lay-up, and the packaging or folding up of the array. It appears advantageous to have a frame or supporting member around the substrate for attaching to handling fixtures and providing a measure of stiffness for handling. The beams and cross stiffeners provide this support on the segmented beam design, as on many of the completely semi-rigid approaches. The concepts presenting problems in this respect are those using completely flexible substrates. Some area of the substrate would have to be left available to provide for attachment of handling devices.

The initial design of the segmented beam concept presented problems in folding, and providing a package suitable for dynamic loads. A lightweight foam core was conceived on which the array is wrapped and bumper pads were added to the substrate to overcome this disadvantage, thus providing an excellent method of damping array vibrations and, at the same time, providing a good method of folding the array.

The delicate care required for the manufacture and packaging of the array to ready it for deployment must be complemented by a scheme that is certain to deploy the array without the slightest damage to cells, cover glasses or wiring.

Control of deployment rate is the essential first consideration. The system of slowly paying out cable and ribbon from motor-controlled drums is mechanically very simple, and presents no unknowns or development problems.

The system of wrapping presents a way of folding the array into the required envelope and isolating all cells from the damaging effects of other cells, or other parts of the system. The cushioned core, onto which the array is wrapped, remains with the array until it is no longer required for distributing the deployment loads evenly throughout the array. The semi-rigid array concepts, in general, are good in this respect also, since their cell faces tend to move away from one another when deployed and present no damaging effects. The flexible rolled arrays have minor problems at the beginning of deployment, but, as the array extends, the increased length and weight impose very high loads on the unrolled portion of the array that tend to bend and slide cells which would produce possible cell damage. Tests conducted at Ryan indicate that the thickness of the padding required to prevent cell damage (with still questionable results), would extend the roll size beyond the four-inch envelope. The roll method would be more applicable to a non-spin stabilized craft, where these high loads are not encountered. A method of merely unrolling the array could be employed, rather than a method of restraint against high loads.

Rigidizing the deployed array presents many problems in the design of an adequate, reliable system which will stay within the weight envelope, yet the weight limitation must be thoroughly demonstrated before the method can be used. The segmented beam fulfills all requirements of rigidizing the array in a simple, reliable manner. Many other methods were investigated, which included attachments to the substrate at various points along the side, or at the outer end, in the hope that this type of substrate support could be considered rigidizing. In summary, the weight penalty involved combined with the development and shadow problems, plus reliability considerations, presented no reasons to consider these systems superior or even equal to the segmented beam which provides support throughout the entire length.

Several considerations, which Ryan feels should be included, are applicability of concept to other shape and size envelopes, larger arrays, and modular approaches. The size and shape of the segmented beam package may be changed by changing the length of the long segments or changing the number of segments. Width of array may be increased by adding beams as transverse panel buckling becomes critical. Extra length is rigidized by simply adding another segment of beam. If loads normal to the panel are expected, additional beam height at the base could be provided.

A method of modularizing is shown on the detailed drawing (Ref. Sec. 3.4.1.4, Fig. 3 Sec. DD). By removing a connecting pin, the sections may be parted, and an interchangeable module may be inserted into the array to replace another if required. Since the frequency of module replacement is expected to be very low, and probably would occur only as a result of damage, a terminal for wire connection was not provided in the harness. Wires running from modules would be re-connected by a soldered splice. The problem of providing modules does not appear to be difficult for any of the concepts. The semi-rigid hinged panels lend themselves best to this feature, but the incorporation of module disconnects is mainly one of designing a joint which will take the load, and which is compatible with the particular concept.

Ryan's evaluation is that the segmented beam concept proposed is the most reasonable and reliable solution to an unfurling array system for a spin-stabilized craft.

3.4 CONSTRUCTION, OPERATION AND TECHNICAL ANALYSIS OF SEGMENTED BEAM CONCEPT

3.4.1 General

The requirement for lightweight structure necessitates a highly loaded structure. A part that does not take maximum advantage of the material strength is not efficiently designed. Concentrated loads then must be distributed sufficiently to eliminate local failures. The critical loads must be closely analyzed whether their source is manufacturing, handling, environment or operation. The design for construction of this assembly is based on this philosophy coupled with a material selection that is compatible with the environment.

3.4.1.1 Substrate Construction (Ref. Fig. 3.)

The basic substrate is a combination of alternate long semi-rigid sections of RP 7A-828-128 epoxy impregnated glass cloth, .0085" thick and flexible short sections of Armalon 403-108 .0035" thick (Teflon coated 108 glass cloth). Two methods of joining these sections are shown, depending on the preference as to a modular or one piece array. (Ref. Fig. 3 Sections C-C and D-D.) The thicker semi-rigid sections provide enough strength to provide good handling and cell mounting capabilities and the thinner, more flexible sections provide the bending capability between cells which is required at the folds. Longitudinal beams and beam segments fabricated from .032" thick 6061 aluminum sheet and 5/32" diameter x .020" wall 6061 aluminum tube, of a cross-section shown in Fig. 3, detail of -7 and -9, are bonded directly to the substrate along both sides for the entire substrate length. The length of the beam is divided into various sections or segments to accomodate folding within the design envelope. (For rigidizing the beam refer to Para. 3.4.1.3.) Cross stiffness is provided by the hinge pin for modular arrays or cross stiffener rods for one piece array (Ref. Fig. 3, Section F-F). A T-shaped cross beam of machined 6061 aluminum alloy is bonded to the substrate at the outer end to take the loads from the deployment control straps. Buffer pads of .150" thick flexible polyurethane foam are bonded (20) places on each side of the substrate to transfer vibration loads to the core for effective damping. Rectangular sections of fiberglass are bonded in 10 places along one edge of one side of the substrate to serve as mounting pads for electrical connectors and diodes. Strips of .015" thick x .395" wide Fiberglas, to simulate the solar cells stiffening effect, are bonded to the inner end of the substrate. Cells are not used in this area since it is shaded by the rotating frame shelf. The substrate is shown attached to the structure by bonding and the use of a clamping strip. An alternate quick disconnect method could be used here to facilitate installation and removal of the array. All bonded joints are designed to take out loads in shear. Where tension loads are expected, additional contact area was provided to reduce bond line loading.

The substrate constructed, as described above will serve as a mounting for five areas of 2x2 cm solar cells approximately 12" x 18.6" both sides and four areas of 1x2 cm solar cells approximately 3.5" x 12". The method of cell layup and wiring is shown on the electrical installation drawing Figure 7. The design of the 1x2 cell modules that are used in the flex area is shown on Figure 8 as -5 and -7. The array when complete with cells will provide seven 28 volt supply units each side of the panel. (Each large, semi-rigid area providing 28 volts and two groups of two small flexible areas providing 28 volts.)

The core (Ref. Fig. 3) onto which the array is wrapped is fabricated from rigid polyurethane foam of 2 pound density. The shape provides maximum support at array folds where required, but eliminates weight by removing areas where support is not required. The core is faced with 3/32" soft foam plastic to provide a cushion for the cells that contact this area.

3.4.1.2 Mount Frame (Ref. Fig. 4)

The frame assembly is basically constructed from .025" sheet Alclad 2024 material. The base is triangular in shape and is designed for hydropress fabrication. A rotating head is built up from brake formed sections of .025" sheet Alclad 2024 and connected to the base by a fitting which allows the head to rotate to a pre-determined angle after the array has deployed (Ref. Fig. 4, Sec. C-C). This fitting provides for connection to a mechanism which would furnish rotational force, but this mechanism is not part of this package. The rotating head and frame are equipped with various brackets and bearing mounts which support the motor, shafts, springs, pulleys and reels which are required for rate control and beam rigidizing (Ref. Sec. 3.4.2.2 and 3.4.2.3). During boost phase and during deployment, loads are fed from the reels and straps, and rotating head which support the array, into the spacecraft structure by 4 mounting lugs on the frame. After deployment, array loads are transferred directly to the rotating heat and reacted at the upper two mount lugs only.

3.4.1.3 Mechanisms (Ref. Fig. 5 and Fig. 6)

The mechanisms used in this concept are for the purpose of controlling deployment rate and providing panel rigidity. A description of the operation of this system is contained in Para. 3.4.2 which will describe in detail how the mechanisms function. The items which comprise the array mechanism are as follows:

1 - Electric Motor BuOrd Size 8, 6 Pole, 13 or 26 Volts

1 - Gear Box (Mates directly to above motor, 79 to 1 reduction)

2 - Drive Rods

2 - Deployment Ribbon Reels

2 - Miniature Overrunning Clutch

2 - Cable Reels

4 - Spring Leaf Brakes

2 - Idler Reel for Deployment Ribbon

2 - Deployment Cables and Disconnect Hooks

2 - Deployment Ribbons

2 - Beam Tension Cables

1 - Negator Spring and Track

1 - Deployment Ribbon Release Latch

3 - Idler Pulleys

3.4.2 Operation

The operation of the concept is best described in three phases which are presented in the next sections as Packaging, Deployment and Rigidization.

3.4.2.1 Packaging

The procedure to be followed in packaging the array is as follows: Cock the negator spring to allow folding the beams. Using the core to support the substrate, proceed to wrap the array around the core, working from the outer end to the inner. When the array is in a position 90° from the frame, attach the deployment ribbon. Rotate the folded array the last 90° and attach the retaining cables. Remove slack from the cables and ribbon by running the motor in reverse. This operation brings all damping pads into contact and provides a packaged configuration ready for mounting on the spacecraft.

3.4.2.2 Deployment (Ref. Fig. 5)

The spacecraft has been placed in orbit and stabilized by spinning before energy is required from the solar arrays. At this time deployment is commanded by activating an electric motor. As the motor rotates the two retaining cables are payed out and allow the folded array to swing slowly out 90° to a position normal to the frame assembly. These cables are wrapped on spools at each side of the frame assembly (Ref. Fig. 5 Detail F) and the outer end attached to the folded array by a formed clip which spreads the load to the segmented beam and provides for a disconnect fitting (Ref. Fig. 5 View A). The load path through this first movement is as follows: The spinning craft causes the folded array to exert a high centrifugal force on the cables and the array tries to pull itself free from the frame. Since the array is permanently attached to the frame at the upper end, it will take one-half of this load and provide a point about which the array package will rotate. The remainder of the load is transmitted to the two cables which, in turn, loads a drive shaft torsionally to transfer the load to a right angle drive of 16 to 1 ratio, and then into a miniature gear box of 79 to 1 ratio. This high reduction ratio prevents any rotation of the shafts except by the motor. The motor would be driven by the deploying array if it were not for the gear reduction stopping this load transfer. The motor, therefore, must only supply enough torque to overcome friction in the reduction gears and would be running under practically a no-load condition.

As the array reaches this 90° position, the load in the cables is reduced to zero, since half of the load that was originally taken by the cables is now transferred to the substrate and deployment ribbons (Ref. Fig. 5-5). At this time, the motor continues to operate to turn the cable spools to a position where the cable is released. The free end of the cable swings out due to centrifugal force and thus rotates the clip which is attached to the array. As the clip rotates, it releases from the array and the entire cable is ejected into space.

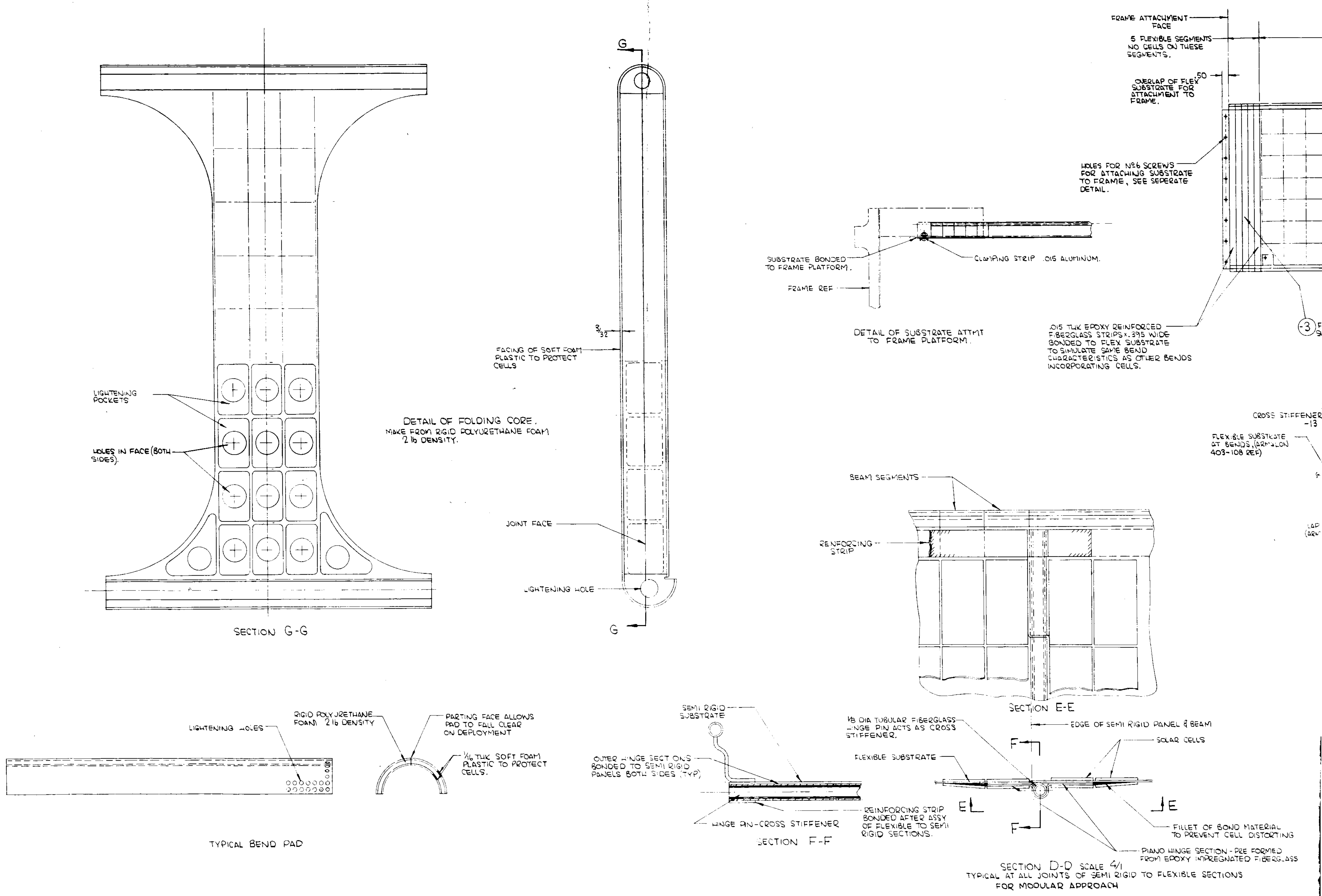
The array, still under load, is trying to unfurl itself but is now restrained by two ribbons of silicon-coated glass cloth. The ribbons attach at one end to a latch mechanism, extend over the array on to idler rollers (Fig. 4-37) and then on to 2 ribbon reels (Ref. Fig. 5 Detail F). The ribbon reels are mounted on the same drive shaft that supports the cable reels. A miniature overrunning clutch is incorporated in the ribbon reels to allow the cable reels to rotate, as previously described, without moving the ribbon reels. Now a load is introduced into these ribbon reels by the array and the overrunning clutch engages the shaft. The reels are now engaged to the electric motor through a gear reduction. The deployment rate is controlled, as explained, for cable deployment. As centrifugal force extends the array to its full open position, one end of the ribbon is released from the reels and the other end is released by a latch activated by the negator spring device explained in the following section. Both ends free, the ribbons move away from the spacecraft into space.

3.4.2.3 Rigidizing

The final operation performed by the mechanism is to rigidize the array. To understand this sequence completely, let us first briefly review the operation of the segmented beam. The beam itself is composed of segments which are bonded to the substrate at their base, and butted together so as to appear as one continuous beam when the substrate is extended in a flat condition. When the substrate is folded, the beam is free to separate at the outer surface, thus creating small pie-shaped spaces between the segments. To bring the beam back to its straight condition, the spaces must be closed by some method. The method used here is to provide a tube at the side of the beam not bonded to the substrate. A small, flexible cable is fed through this tube and attached to one end of the beam. To draw the outer sides of the segments together, and thus straighten and rigidize the beam, a tension force is applied to the cable and the resulting rigidizing is accomplished.

A tensioning device must be used which is capable of maintaining a sufficiently low tension load in the cable to remove slack as the array unfolds, but still be capable of increasing the tension for final beam rigidizing. To accomplish this, the beam cables are routed to a negator spring device (Ref. Fig. 6) located in the rotating head. The negator spring resembles the main spring in a clock, but is wound and heat treated in such a manner that it exerts a constant load as it is uncoiled and

Figure 3. Substrate Installation - Deployable Solar Array


LIGHTENING POCKETS
HOLES IN FACE (BOTH SIDES).
SECTION G-G
DETAIL OF FOLDING CORE.
MAKE FROM RIGID POLYURETHANE FOAM 2 lb DENSITY.
G
3/32
FACING OF SOFT FOAM PLASTIC TO PROTECT CELLS
JOINT FACE
LIGHTENING HOLE
LIGHTENING HOLES
RIGID POLYURETHANE FOAM 2 lb DENSITY
PARTING FACE ALLOWS PAD TO FALL CLEAR ON DEPLOYMENT
1/16 THK SOFT FOAM PLASTIC TO PROTECT CELLS.
TYPICAL BEND PAD
FRAME ATTACHMENT FACE
5 FLEXIBLE SEGMENTS NO CELLS ON THESE SEGMENTS.
.50
OVERLAP OF FLEX SUBSTRATE FOR ATTACHMENT TO FRAME.
HOLES FOR No 6 SCREWS FOR ATTACHING SUBSTRATE TO FRAME, SEE SEPERATE DETAIL.
SUBSTRATE BONDED TO FRAME PLATFORM.
CLAMPING STRIP .015 ALUMINUM.
FRAME REF
DETAIL OF SUBSTRATE ATTMT TO FRAME PLATFORM.
.015 THK EPOXY REINFORCED FIBERGLASS STRIPS x .395 WIDE BONDED TO FLEX SUBSTRATE TO SIMULATE SAME BEND CHARACTERISTICS AS OTHER BENDS INCORPORATING CELLS.
CROSS STIFFENER -13
FLEXIBLE SUBSTRATE AT BENDS, (ARMALON 403-108 REF)
BEAM SEGMENTS
REINFORCING STRIP
SECTION E-E
SEMI RIGID SUBSTRATE
OUTER HINGE SECTIONS BONDED TO SEMI RIGID PANELS BOTH SIDES (TYP)
HINGE PIN-CROSS STIFFENER
SECTION F-F
REINFORCING STRIP BONDED AFTER ASSY OF FLEXIBLE TO SEMI RIGID SECTIONS.
1/8 DIA TUBULAR FIBERGLASS HINGE PIN ACTS AS CROSS STIFFENER.
FLEXIBLE SUBSTRATE
EDGE OF SEMI RIGID PANEL & BEAM
SOLAR CELLS
F
E
FILLET OF BOND MATERIAL TO PREVENT CELL DISTORTING
PIANO HINGE SECTION - PRE FORMED FROM EPOXY IMPREGNATED FIBERGLASS
SECTION D-D SCALE 4/1
TYPICAL AT ALL JOINTS OF SEMI RIGID TO FLEXIBLE SECTIONS
FOR MODULAR APPROACH

CONCEPT / CRITERIA	CONSTRUCTION	MECHANISMS ETC	CELL MOUNTING PROVISIONS	PRACTICALITY FOR I-G FAB & HANDLING	PACKAGING	DEPLOYMENT	RIGIDIZING	PROBLEM AREAS	ADVANTAGES	ADAPTABILITY TO LARGE ARRAYS	RELIABILITY	READER EVALUATION REMARKS	SUMMARY OF REMARKS
1. SEGMENTED BEAM — FLEXIBLE & SEMI-RIGID SUBSTRATE STABILIZED BY BEAMS & DEPLOYED BY CENTRIFUGAL FORCE. SUBSTRATE RIGIDIZED BY TENSIONING CABLES IN BEAMS	CURVED SECTIONS OF FLEXIBLE SUBSTRATE JOIN TO STRAIGHT SEMI-RIGID SECTIONS. FORMED SHEET METAL BEAMS BOND IN PLACE SUPPORTED BY FRAME	SMALL ELECTRIC MOTOR ACTS AS RETARDING FORCE ON CABLES & STRAPS. NEGATOR SPRING DEVICE ACTS AS BEAM CABLE TAKEUP & TENSIONING MECH.	LONG FLAT SECTIONS PROVIDE OPPORTUNITY FOR USE OF 2x2 CELLS OVER MAJOR AREA. 1x2 CELLS REQD IN BEND AREAS. MODULAR CONCEPT IS APPLICABLE	CONSTRUCTION OF MODELS & TEST SPECIMENS REVEALED NO MAJOR PROBLEMS. NO EXOTIC MATERIALS OR PROCESSES REQD.	INCORPORATION OF A FOAM CORE & DAMPER PADS RESULTS IN A SOLID PACKAGE WHICH IS FURTHER SECURED BY STRAPS & CABLES. NO ENVELOPE PROBLEMS.	MORE COMPLEX THAN SOME SYSTEMS BUT ALL MOVEMENT INVOLVES SIMPLE DEVICES WHICH ARE ADEQUATE TO CONTROL THIS PHASE	ACCOMPLISHED VERY SIMPLY & RELIABLY WITH TENSIONING CABLES IN BEAM SPARS. SUPPORT PROVIDED TO ENTIRE LENGTH.	SHADOW CAST BY BEAM ON NON SUN ORIENTED CRAFT	ADAPTABLE TO VARIOUS ENVELOPES-EASILY RIGIDIZED-ONE END REMAINS FIXED FOR EASE OF ELECTRICAL CONNECTION & DEPLOYMENT CONTROL	ADDITIONAL SEGMENTED BEAMS FOR STABILIZING ADDED WIDTH WOULD BE REQ'D ON LARGE ARRAYS	FEW COMPONENTS INVOLVED-ONLY MECHANICAL SYSTEMS USED & SIMPLICITY OF SYSTEMS INDICATES A GOOD RELIBILITY		CONCEPT PACKAGES EASILY INTO REQ'D ENVELOPE WITH SPACE TO SPARE IF EXTRA LENGTH IS REQD. THE SYSTEM OF RIGIDIZING IS SIMPLE & RELIABLE CONCEPT IS ADAPTABLE TO LARGE ARRAYS. MODULAR CONCEPT IS APPLICABLE & MAJOR AREA IS USABLE FOR INSTL OF 2x2 CELLS DEPLOYMENT & RATE CONTROL ARE NOT MAJOR PROBLEMS
2. ROLL-OUT — FLEXIBLE SUBSTRATE IS ROLLED ON TO 2 ROLLERS. TELESCOPING TUBES ALONG SIDES ARE PRESSURIZED TO EXTEND & RIGIDIZE SUBSTRATE	ONE LENGTH OF FLEXIBLE SUBSTRATE WRAPPED ON SHEET METAL ROLLERS. SEAMLESS TUBING & SHEET METAL FRAME	RETARDING MOTOR OR BRAKE-PRESSURE BOTTLES-TORSION SPRINGS-TELESCOPING STRUTS-SUP GUIDES MOVING ELECTRICAL CONNECTORS.	CONCEPT REQUIRES 1x2 CELLS & ADDED SPACING TO PROVIDE FOR BENDING, THIS RESULTS IN LOST AREA BETWEEN CELLS & HIGH INSTL COST	WOULD REQUIRE HANDLING FRAMES TO SUPPORT LONG FLEXIBLE AREA	ADEQUATE SPACE FOR THIS DESIGN-SOME TYPE OF SUPPORT WOULD BE REQ'D TO DAMP SUBSTRATE VIBRATION BETWEEN ROLLERS	FAIRLY SIMPLE METHOD. BALANCING EXTENDING & RETARDING FORCE AT VARIOUS RPM MAY PROVE TRICKY. — TILTING SUBSTRATE ALONE IS A PROBLEM	SUPPORTED ONLY AT POINTS CONNECTING TO SPARS	SYNCHRONIZING STRUT EXTENSION,— ELECTRICAL CONNECTION, ATTACH OF SUBSTRATE TO EXTENDED STRUTS,	DEMONSTRATES FLEXIBILITY REQUIREMENT TO A HIGH DEGREE	LARGE UNSUPPORTED AREAS OF CELLS BETWEEN ROLLERS PRESENT VIBRATION PROBLEMS	ELECTRICAL CONNECT AT END & PRESSURIZED STRUT SYSTEM ARE QUESTIONABLE RELIABILITY AREAS		THE PROBLEM OF CONTROLLING THE FREE END & PROVIDING RELIABLE ELECTRICAL CONNECTION OFFERS MANY DISADVANTAGES— ENTIRE SURFACE MUST MOVE OVER ROLLERS & WILL REQUIRE 1x2 CELLS WITH INCREASED SPACING & RESULTING AREA LOSS.—ATTACHING TO SPAR FOR RIGIDIZING PRESENTS PROBLEMS
3. PLEATED — SEMI-RIGID PANELS ARE ATTACHED TO LAZY TONG BEAMS & DEPLOYED & RIGIDIZED BY A CABLE SYSTEM WHICH ACTUATES LAZY TONGS	SEMI-RIGID SUBSTRATE IS FORMED IN SMALL SECTIONS & JOINED BY FLEXIBLE HINGES LAZY TONGS OF SHEET METAL MOUNTED ON HYDROFORMED BASE	TORSION SPRINGS - ELECTRIC MOTOR - PULLY & CABLE SYSTEMS—ACTUATED LAZY TONGS	A LOSS OF AREA DUE TO CELL INTERFERENCE AT BENDS & AREA REQD. FOR HINGES IS EXPECTED THE CONCEPT HAS GOOD MODULAR ASPECTS	THE SUBSTRATE IS WELL SUPPORTED BY FRAMES & WOULD BE EASILY FABRICATED & LAYED UP WITH CELLS. DAMPING PADS WOULD BE REQD. TO ELIMINATE SLOSH	CONCEPT COULD PROVIDE EXTRA LENGTH OF SUBSTRATE IF REQD OR BE PACKAGED IN SHORTER ENVELOPE.—	LAZYTONGS MAY BE USED TO ACTUATE OR RETARD FOR SPIN OR NON SPIN SYSTEMS	TRANSVERSE HINGES RETAINING LOADS TO LAZY TONG STRUTS PROVIDE EXCELLENT RIGIDITY WHEN DEPLOYED	BEAM SHADOW-	FOLDED PANELS STIFFEN PACKAGE FOR VIBRATION LOADS	SECTIONS WOULD REQUIRE ADDITIONAL LAZY TONG BEAMS OR STIFFENERS BUT OTHERWISE IS ADAPTABLE	SEE COMMENTS FOR CONCEPT #1		DOES NOT DEMONSTRATE A TRULY FLEXIBLE SUBSTRATE BUT GIVES A WELL RIGIDISED AND RELIABLE METHOD TO EXTEND A FOLDING MODULAR ARRAY
4 ROLL & FOLD — ALTERNATING SECTIONS OF FLEXIBLE & SEMI-RIGID SUBSTRATE ARE WRAPPED ONTO DRUM & DEPLOYED BY ROTATING DRUM	PERFORATED SHEET METAL DRUM — ALTERNATING SECT. OF FLEXIBLE & SEMI-RIGID SUBSTRATE FORMED ARMS & SEAMLESS TELESCOPING TUBING	ESCAPEMENT MOTOR PRESSURE BOTTLE SYSTEM - TELESCOPING TUBES, GUIDE HOOPS TORSION SPRINGS	SEE COMMENTS FOR CONCEPT NO. 1	SUBSTRATE BEFORE PACKAGING WOULD REQUIRE HANDLING FRAMES	THE ROTATING DRUM PROVIDES EXCELLENT SUPPORT FOR VIBRATION DAMPING & A CONVIENENT METHOD FOR WRAPPING	CONTROLL IS EXCELLENT & EASILY ACCOMPLISHED BY A MOTOR CONTROL OF DRUM SPEED	SUBSTRATE IS NOT RIGIDIZED DIRECTLY BUT WOULD BE PULLED TAUT BY CROSS BAR AT TUBE ENDS	SYNCHRONISING TUBE EXTENSIONS & RATE CONTROL DIFFICULTY TO STOW WITHIN PACKAGE LIMITS.	USE IS MADE OF STOWING DRUM TO MOUNT CELLS ON BOTH SIDES.	SIZE WOULD BE LIMITED TO OPTIMUM SIZE OF TELESCOPING TUBES.	FAIR TO GOOD RELIABILITY. ERECTING WOULD LARGELY DEPEND ON ABILITY OF TUBES TO EXTEND IN UNISON.		DEMONSTRATES THE APPROACH TO A MIXED USE OF SEMI RIGID AND FLEXIBLE SUBSTRATES. DOUBLE ROLLERS ARE USED TO MINIMIZE POSSIBLE DAMAGE TO CELLS AS ON A TIGHTLY ROLLED SINGLE ROLLER.
5. SINGLE STRUT & PANELS — SEMI RIGID PANELS ARE ATTACHED TO FOLDED HINGE BEAM. TORSION SPRINGS AT HINGES DEPLOY & LOCK BEAM FOR RIGIDIZING	FORMED METAL STRUT & HINGES - TUBULAR SUBSTRATE FRAMES HYDROFORMED MOUNT FRAME	TORSION SPRINGS EXTEND STRUTS ASSISTED BY CENTRIFUGAL FORCE, CABLE & ELECTRIC MOTOR CONTROL RATE.	2x2 CELLS ARE MOUNTED ON BOTH SIDES OF A SEMI RIGID SUBSTRATE.	REASONABLY GOOD HANDLING FEATURES, THE SEMI RIGID PANELS BEING LESS LIABLE TO DAMAGE.	ARRAY FOLDS INTO PACKAGE LIMITATIONS WITH EASE. SEPARATE PROTECTIVE MATS ARE REQUIRED BETWEEN CELL FACES.	SINGLE CENTRE STRUT MAKES INITIAL EXTENSION BY TORSION SPRINGS. CENTRIFUGAL LOADS TAKE OVER. RATE IS CONTROLLED BY CABLE & ELECTRIC MOTOR.	ONLY FAIR RIGIDISATION DUE TO PANELS NOT BEING SUPPORTED AT EDGES, POOR TORSIONAL RESISTANCE.	INSTABILITY DURING MANOEUVRE AND GROUND DEMONSTRATION	LIGHT STRUCTURE AND SIMPLE MECHANISM, GOOD MODULAR CAPABILITIES, SINGLE STRUT ELIMINATES NEED TO SYNCHRONISE.	REASONABLY ADAPTABLE TO LARGER ARRAYS BY INCREASING BEAM SIZE.	GOOD RELIABILITY DUE TO FEW AND SIMPLE MECHANISMS.		DOES NOT DEMONSTRATE A TRULY FLEXIBLE SUBSTRATE BUT GIVES A SIMPLE AND INEXPENSIVE APPROACH TO A MODULAR FOLDING ARRAY, LIGHT IN WEIGHT.
6. TELESCOPING CHANNELS — ENTIRE PACKAGE ROTATES 90° & CHANNELS EXTEND TO PROVIDE SUBSTRATE SUPPORT & DEPLOY ROLLED SUBSTRATE	SHEET ALUMINUM TELESCOPING CHANNELS, FRAME, STOWING AND TAKE-UP REELS.	SPRINGS AIDED BY CENTRIFUGAL LOADS RAISE FRAME. NEGATOR SPRINGS EXTEND CHANNELS. RATE IS CONTROLLED BY CABLE & ELECTRIC MOTOR.	2x2 CELLS ARE MOUNTED ON FACES OF FRAME 1x2 CELLS ARE MOUNTED ON BOTH SIDES OF A FLEXIBLE SUBSTRATE.	HANDLING OF STRUCTURE WOULD NOT PRESENT ANY UNDUE DIFFICULTY. FLEX SUBSTRATE WOULD REQUIRE CARE PARTICULARLY DURING STOWAGE.	FLEXIBLE PORTION OF SUBSTRATE IS STOWED ON DOUBLE REELS, WITH PROTECTIVE MAT BETWEEN. MAT IS WOUND ON TAKE-UP REEL ON DEPLOYING.	ON DEPLOYMENT ENTIRE PACKAGE IS RAISED, THEREON THE TELESCOPING CHANNELS EXTEND. FIRST MOTION IS RATE CONTROLLED BY CABLE.	BEAMS OFFER GOOD BENDING RESISTANCE. BEADED EDGE ON SUBSTRATE SLIDES IN GUIDES ON CHANNELS. SUBSTRATE HAS TRANSVERSE STIFFENING RODS.	BEAMS WOULD CAST SHADOWS ON CELLS. SUBSTRATE WOULD DRAG OVER ROLLERS ON DEPLOYING. ELECTRICAL CONNECTIONS WOULD POSE DIFFICULTIES.	USE IS MADE OF RIGID FRAME FOR ¼ OF ARRAY. CHANNELS OFFER GOOD BENDING RESISTANCE.	REASONABLE ADAPTABILITY BY INCREASING BEAM & FRAME SIZE	FAIR RELIABILITY, NUMEROUS MECHANICAL MOTIONS HAVE TO SEQUENCE CORRECTLY TO DEPLOY ARRAY.		A COMBINATION OF SEMI RIGID & FLEXIBLE SUBSTRATES. ADVANTAGE IS TAKEN OF FRAME STIFFNESS TO BECOME PART OF THE ARRAY. SUBSTRATE IS WOUND ON DOUBLE ROLLERS TO MINIMIZE POSSIBLE CELL DAMAGE ON TIGHTLY ROLLED SINGLE DRUM.
7. TELESCOPIC TUBES & PANELS — ACCORDIAN FOLDED SEMI-RIGID PANELS ARE EXTENDED BY TELESCOPING TUBES	2 SETS OF ALUMINUM TELESCOPING TUBES IN ALUMINUM SHEET FRAME. SHEET ALUMINUM STAY STRUTS.	SPRINGS RAISE TELESCOPING TUBES & GAS BOTTLE EXTENDS TUBES.	2x2 CELLS ARE MOUNTED ON EITHER SIDE OF A SEMI-RIGID SUBSTRATE. SUBSTRATE HAS FLEXIBLE HINGES AT FOLD POINTS.	HANDLING WOULD NOT PRESENT ANY UNDUE DIFFICULTY. THE SEMI-RIGID PANELS OFFER GOOD SHEAR RESISTANCE.	THE PANELS WOULD REQUIRE SEPARATE PROTECTING MATS BETWEEN FACES. ADEQUATE SPACE FOR THIS ARRAY IN THIN PACKAGE.	TORSION SPRINGS RAISE TUBES & GAS BOTTLE EXTENDS THEM. THE SEMI RIGID PANELS AUTOMATICALLY ERECT.	THE TELESCOPING TUBES OFFER FAIRLY GOOD RIGIDITY. THE PANELS ARE ONLY ATTACHED TO THE TUBES AT THEIR HINGE POINTS.	THE EXTENSION OF THE TUBES WOULD HAVE TO BE SYNCHRONISED TO ENSURE EQUAL DEPLOYMENT.	ABILITY TO CONTAIN THE FOLDED ARRAY WITHIN THE PACKAGE WITH EASE. SUITABLE FOR THE MODULAR APPROACH.	DOUBTFUL FOR REALLY LARGE ARRAYS DUE TO DIFFICULTY OF HANDLING TELESCOPING TUBES.	FAIRLY GOOD RELIABILITY DEPENDING ON THE TUBES OPENING SYNCHRONOUSLY.		DOES NOT DEMONSTRATE A TRULY FLEXIBLE SOLAR ARRAY. SOME DEVELOPMENT WOULD BE REQUIRED TO GET TUBES TO SYNCHRONISE. REASONABLY GOOD TORSIONAL STABILITY DUE TO PANELS BEING ABLE TO TAKE SHEAR LOADS.
8. FOLD OUT SUPPORTS — TORSION SPRING LOADED STRUTS EXTEND TO PROVIDE SUPPORT & DEPLOY PANEL	SHEET ALUMINUM ARMS STOWING REELS AND FRAME.	SPRING LOADED ARMS FOR RIGIDISING, RATE CONTROL MECHANISM IN STOWING REEL. SPRING LOADED MAT TAKE-UP REEL.	2x1 CELLS ARE MOUNTED ON BOTH SIDES OF FLEX SUBSTRATE & STOWED ON DOUBLE STOWING REELS.	CARE WOULD BE NEEDED IN HANDLING THE SUBSTRATE PARTICULARLY WHEN STOWING ON REELS.	THE HINGED ARMS ARE STOWED ON EITHER SIDE OF STOWING REELS.	THE SPRING LOADED ARMS ERECT BY TORSION SPRINGS AT JOINTS PLUS CENTRIFUGAL LOADS. SUBSTRATE IS PULLED FROM DRUMS WHICH IS RATE CONTROLLED	THE PANEL ITSELF IS NOT RIGIDISED & RELIES ON RODS FOR TRANSVERSE STIFFENING.	LACK OF EDGE STIFFENING FOR PANELS. CELLS WOULD BE DRAGGED OVER REELS ON DEPLOYMENT. ELECTRICAL CONNECTIONS OF THE DOUBLE REEL.	RELATIVELY SIMPLE DEPLOYMENT AND LIGHTNESS.	DOUBTFUL DUE TO UNSUPPORTED PANEL.	FAIRLY GOOD RELIABILITY DUE TO FEW MECHANICAL PARTS.		ALLOWS DEMONSTRATION OF A FULLY FLEXIBLE SOLAR ARRAY. MANOEUVRES WOULD CAUSE A PROBLEM WITH THE UNSUPPORTED PANEL.
9. DUAL SUPPORTS & PANELS — SPRING LOADED HINGED BEAMS EXTEND & LOCK TO SUPPORT SEMI-RIGID SUBSTRATE	SHEET ALUMINUM CHANNELS & FRAME.	BEAMS ARE SPRING LOADED TO EXTEND & RATE IS CONTROLLED BY CABLE & ELECTRIC MOTOR	2x2 CELLS ARE MOUNTED ON SEMI RIGID PANELS SET ON EITHER SIDE OF BEAMS.	HANDLING WOULD NOT PRESENT ANY UNDUE DIFFICULTY. THE STIFF PANELS WOULD FOLD EASILY	THE ARRAY IN STOWED CONDITION WOULD BE WELL SUPPORTED FROM VIBRATION. PROTECTIVE MATS WOULD BE REQUIRED BETWEEN FACES.	A LIGHT SPRING LOAD WOULD MAKE INITIAL DEPLOYMENT ASSISTED BY CENTRIFUGAL FORCE. RATE CONTROL WOULD BE BY CABLE & ELECTRIC MOTOR	THE PANELS WOULD BE RIGID IN THEMSELVES AND LOCKED AT THE HINGES AFTER DEPLOYMENT.	THE PROTECTIVE MATS WOULD HAVE TO BE CAST LOOSE & AWAY BY CENTRIFUGAL FORCE.	GOOD STIFFNESS QUALITIES & SIMPLE DEPLOYMENT. GOOD MODULAR ASPECTS.	CAN BE READILY ADAPTED TO LARGER ARRAYS.	GOOD RELIABILITY DUE TO SMALL NUMBER OF MECHANICAL PARTS.		DOES NOT DEMONSTRATE A TRULY FLEXIBLE SOLAR ARRAY BUT ALLOWS LIGHTWEIGHT SEMI RIGID PANELS TO BE STOWED AND DEPLOYED IN A SIMPLE MANNER.
10. LARGE LAZY TONG BEAMS — TORSION SPRINGS EXTEND BEAMS & SUBSTRATE IS REELED FROM 2 ROLLERS	MACHINED ALUMINUM ARMS & SHEET ALUMINUM FRAME	INITIAL EXTENSION BY TORSION SPRINGS AT ARM INTERSECTIONS. RATE CONTROLLED BY CABLE & MOTOR RESTRAINING ARMS.	1x2 CELLS ARE MOUNTED ON A FLEXIBLE SUBSTRATE. SUBSTRATE HAS BEADED EDGE TO PASS THRU GUIDES AT ARM INTERSECTIONS.	HANDLING WOULD NOT PRESENT ANY UNDUE DIFFICULTIES. FLEXIBLE SUBSTRATE WOULD REQUIRE CAREFUL HANDLING.	THE SUBSTRATE WOULD BE WOUND ON A SINGLE DRUM. FOLDED ARMS WOULD NEST ON EITHER SIDE.	ARMS WOULD EXTEND UNDER CENTRIFUGAL FORCE, PULLING SUBSTRATE FROM ROLLER.	TRANSVERSE RODS SET IN SUBSTRATE WOULD ACT AS STIFFENERS.	ARMS WOULD CAST SHADOWS ON CELLS, SUBSTRATE WOULD ONLY BE ATTACHED AT ARM INTERSECTIONS.	LAZY TONG WOULD PROVIDE GOOD BEAM STRENGTH AND GOOD RELIABILITY AS MECHANISMS ARE SIMPLE.	GOOD ADAPTABILITY TO LARGER ARRAYS.	VERY GOOD.		A RELATIVELY SIMPLE AND RELIABLE SYSTEM. DEMONSTRATES A TRULY FLEXIBLE ARRAY WELL SUPPORTED. PROTECTIVE MAT WOULD BE REQUIRED BETWEEN CELL FACES.
11. ROLL FORMED SUPPORT — PERFORATED METAL STRIP IS MOTOR FED THROUGH ROLLERS TO FORM SUPPORT. SUBSTRATE UNROLLS FROM (1) ROLL	ALUMINUM PARTIALLY PRE-FORMED STRIP. NYLON DRIVE & FORM ROLLERS. SHEET ALUMINUM FRAME.	SMALL ELECTRIC MOTOR GEARED TO FORM TUBE AT LOW SPEED THRU NYLON FORMING ROLLERS.	1x2 CELLS WOULD BE MOUNTED ON A FLEXIBLE SUBSTRATE.	WHENEVER THIS CONCEPT WAS DEMONSTRATED THE FORMED TUBE WOULD BE DISCARDED BEFORE REPACKAGING.	SUBSTRATE WOULD BE WOUND ON SINGLE DRUM. PROTECTIVE MAT WOULD BE INTERWOUND. SPRING LOADED TAKE-UP DRUM WINDS UP MAT.	MOTOR DRIVEN FORM SPOOLS PULL STRIP THROUGH TO FORM SEAMED TUBE. SUBSTRATE IS PULLED FROM DRUM.	SUBSTRATE WOULD HAVE TRANSVERSE STIFFENING RODS AT INTERVALS. IF DOUBLE TUBES WERE USED EDGE OF SUBSTRATE COULD BE CLAMPED IN SEAMS.	RESEARCH & DEVELOPMENT WOULD BE REQUIRED TO PROVE FEASIBILITY OF SYSTEM. ATTACHING SUBSTRATE TO TUBES WOULD REQUIRE DEVELOPING.	POSITIVE RATE CONTROL. NEED NOT BE FULLY DEPLOYED TO FUNCTION CORRECTLY. ONCE PERFECTED WOULD BE SIMPLE.	COULD BE ADAPTED TO LARGER ARRAYS BY INCREASING MECHANISM & TUBE SIZES.	FAIR TO GOOD.		RESEARCH AND DEVELOPMENT OF TUBE FORMING MECHANISM WOULD TAKE TIME BUT ONCE PERFECTED SHOULD PROVIDE A POSTIVE & RELIABLE SYSTEM. ROLL CONCEPT PRESENTS A PROBLEM OF PROVIDING SUFFICIENT CUSHION THICKNESS TO PREVENT CELL DAMAGE DURING DEPLOYMENT MORE ADAPTABLE TO NON SPIN STABILIZED CRAFT
12. TELESCOPING CHANNELS — CHANNEL FRAME SWINGS OUT & EXTENDS TO UNFURL FOLDED SUBSTRATE	2 SETS OF TELESCOPING SHEET ALUMINUM CHANNELS. SHEET ALUMINUM FRAME.	CHANNELS ARE POSITIVELY EXTENDED BY NEGATOR SPRINGS. RATE CONTROLLED BY CABLE & ELECTRIC MOTOR.	FIRST PART OF CELL ARRAY IS MOUNTED ON FACE OF FRAME. 1x2 CELLS ARE MOUNTED ON FLEXIBLE PORTION.	THE CHANNELS WOULD BE EASILY HANDLED. THE FLEX PORTION WOULD REQUIRE CARE PARTICULARLY IN STOWING.	FLEXIBLE SUBSTRATE WOULD BE STOWED IN LOOPS WITH SEPARATE PROTECTIVE SPACERS IN EACH LOOP.	THE NEGATOR SPRINGS GIVE POSITIVE FORCE FOR EXTENSION, AND RATE IS CONTROLLED BY CABLE & MOTOR.	FLEXIBLE SUBSTRATE CAN ONLY BE ATTACHED TO ONE POINT ON EACH CHANNEL, CHANNELS FORM RIGID BEAMS.	BEAMS WOULD CAST SHADOW ON CELLS, SUBSTRATE WOULD REQUIRE CARE IN STOWING.	ADVANTAGE IS TAKEN OF FRAME TO USE AS CELL AREA. BEAMS OFFER GOOD RIGIDITY.	COULD BE ADAPTED TO LARGER ARRAYS USING LARGER BEAMS ETC.	GOOD RELIABILITY, FEW MECHANICAL PARTS.		THE BEAM DEPTH COULD BE OBJECTIONABLE WITH REGARD TO CAST SHADOWS AND THE LOOP SEPARATORS FOR STOWING A DRAWBACK. GOOD USE IS MADE OF FRAME PACKAGE FOR CELL LAYUP.
13. TELESCOPING PANELS — SEMI RIGID SUBSTRATE IS MOUNTED ACROSS BOTH SIDES OF CHANNELS & ENTIRE PACKAGE SWINGS 90° BEFORE DEPLOYING	2 SETS OF TELESCOPING SHEET ALUMINUM CHANNELS. SHEET ALUMINUM FRAME.	SEE ABOVE.	2x2 CELLS ARE MOUNTED ON SEMI-RIGID SUBSTRATE TO PREVENT BEAMS CASTING SHADOWS	HANDLING WOULD NOT PRESENT ANY UNDUE DIFFICULTY.	THE PANELS WOULD REQUIRE VIBRATION DAMPING PADS BETWEEN FACES IN FOLDED STATE.	SEE ABOVE.	THE SUBSTRATE WOULD BE WELL RIGIDIZED AND WOULD FORM GOOD SHEAR PANELS.	RELATIVELY HEAVY DUE TO DUPLICATION OF SUBSTRATE. ELECTRICAL CONNECTION OF EACH MODULE	GOOD STIFFNESS FROM PANELS. ALLOWS FOR MODULAR APPROACH OF MANUFACTURE.	COULD BE ADAPTED TO LARGER ARRAYS USING LARGER BEAMS ETC.	GOOD RELIABILITY. THE CHANNELS WOULD EXTEND IN UNISON DUE TO GOOD SHEAR TIE ACROSS PANELS.		THE APPROACH DOES NOT ALLOW DEMONSTRATION OF A FLEXIBLE SUBSTRATE, OTHERWISE A RELATIVELY SIMPLE APPROACH TO FOLDING SOLAR PANELS. ELECTRICAL CONNECTION OF MODULES WOULD PRESENT SOME PROBLEM
14. SINGLE TUBE & DUAL REELS — TELESCOPING TUBE EXTENDS TO UNROLL (2) SUBSTRATE ROLLS	A SINGLE SET OF ALUMINUM TELESCOPIC TUBES, SHEET ALUMINUM FRAME & ROLLERS.	COMPRESSED GAS EXTENDS TUBES. STOWING ROLLERS OFFER RATE CONTROL.	1x2 CELLS ARE MOUNTED ON ONE SIDE OF FLEX SUBSTRATES. DOUBLE SUBSTRATES ARE USED.	CARE WOULD BE REQUIRED TO PREVENT DAMAGE TO SUBSTRATES AND TUBES.	SUBSTRATES WOULD BE WOUND ON SEPARATE DRUMS. REAR FACES OF SUBSTRATES WOULD HAVE PROTECTIVE MATS.	GAS BOTTLE EXTENDS TUBES WHICH PULLS SUBSTRATE FROM ROLLERS. ROLLERS CONTROL RATE OF DEPLOYMENT.	SUBSTRATE EDGES WOULD NOT BE SUPPORTED BUT WOULD BE STIFFENED LATERALLY BY RODS.	SUBSTRATE WOULD BE UNSUPPORTED AT EDGES & TUBE WOULD HAVE NO TORSIONAL STABILITY. DOUBLE SUBSTRATES WOULD INCREASE WEIGHT.	DEMONSTRATES A FULLY FLEXIBLE SUBSTRATE. GETS OVER DIFFICULTIES OF DOUBLE SIDED SUBSTRATE.	NOT ADAPTABLE TO REALLY LARGE ARRAYS DUE TO UNSUPPORTED SUBSTRATE.	GOOD RELIABILITY. A STICKING TELESCOPE SECTION COULD PREVENT DEPLOYMENT.		A GOOD METHOD TO DEMONSTRATE A FULLY FLEXIBLE SUBSTRATE, PARTICULARLY AS IT GETS AWAY FROM THE DIFFICULTIES OF A DOUBLE SIDED ARRAY. POSSIBLE DIFFICULTIES IN MEETING PACKAGE LIMITATIONS.
15. TELESCOPING CHANNELS — CHANNELS ROTATE 90° & EXTEND BY NEGATOR SPRINGS TO UNROLL SUBSTRATE FROM DOUBLE ROLLERS.	2 SETS OF TELESCOPING SHEET ALUMINUM CHANNELS. SHEET ALUMINUM ROLLERS FRAM AND TAKE UP ROLLS.	TENSION SPRINGS ERECT STACKED BEAMS. NEGATOR SPRINGS EXTEND CHANNELS RATE FOR FIRST MOTION IS BY CABLE & MOTOR.	1x2 CELLS ARE MOUNTED ON BOTH SIDES OF A FLEXIBLE SUBSTRATE.	HANDLING WOULD NOT PRESENT ANY UNDUE DIFFICULTY. SUBSTRATE WOULD REQUIRE EXTRA DURING STOWAGE ON ROLLERS.	SUBSTRATE IS WOUND ON DOUBLE ROLLERS WITH A PROTECTIVE MAT BETWEEN SURFACES. MAT IS TAKEN UP ON SEPARATE REEL.	STOWED CHANNELS ARE RAISED TO FIRST POSITION BY TENSION SPRINGS. CHANNELS ARE EXTENDED BY NEGATOR SPRINGS.	SUBSTRATE WOULD BE HELD AT ONE POINT ONLY ON EACH CHANNEL. TRANSVERSE STIFFENING BY RODS IN SUBSTRATE.	INNER END OF SUBSTRATE WOULD DRAG OVER ROLLERS. BEAMS WOULD CAST SHADOW & INNER ELECTRICAL CONNECTIONS ARE PROBLEM.	CHANNELS WOULD GIVE GOOD SUPPORT FOR IG DEMONSTATION.	WOULD BE ADAPTED TO LARGER ARRAYS USING LARGER BEAMS ETC.	FAIR TO GOOD RELIABILITY. USE OF MORE THAN ONE DEPLOYING MECHANISM INCREASES CHANCE FOR MALFUNCTION.		A RELATIVELY RIGID METHOD OF DEMONSTRATING A FULLY FLEXIBLE SUBSTRATE. DOUBLE ROLLERS ARE USED TO STOW SUBSTRATE TO MINIMIZE POSSIBLE DAMAGE OF TIGHTLY ROLLED SINGLE ROLLER.
16. LAZY TONGS & ROLLERS — PACKAGE ROTATES 90° BEFORE LAZY TONGS EXTEND TO PULL ROLLED SUBSTRATE FROM PACKAGE	SHEET OR MACHINED ALUMINUM ARMS. SHEET ALUMINUM FRAME.	FOLDED LAZY TONGS RAISED TO DEPLOY POSITION BY SPRINGS & CENTRIFUGAL LOADS. RATE CONTROL BY CABLE & MOTOR	1x2 CELLS MOUNTED ON BOTH SIDES OF A FLEXIBLE SUBSTRATE.	SEE ABOVE.	SEE ABOVE	PACKAGE WOULD RAISE TO DEPLOY POSITION BY SPRING & CENTRIFUGAL FORCE. LAZY TONGS EXTEND BY CENTRIFUGAL FORCE.	SUBSTRATE IS BEADED AT EDGES & PASSES THRU RETAINERS AT ARM INTERSECTIONS. CROSS STIFFENING RODS SET IN SUBSTRATE.	SEE ABOVE	LAZY TONGS WOULD GIVE GOOD RIGIDITY & SUBSTRATE WOULD BE HELD AT SMALL INTERVALS.	COULD BE ADAPTED TO LARGER ARRAYS USING LARGER LAZY TONGS ETC.	GOOD. SHOULD PROVIDE A RELIABLE METHOD OF DEPLOYMENT & RIGIDIZATION.		A GOOD METHOD OF FOLDING RIGIDIZING BEAMS & METHOD OF DEMONSTRATING A FULLY FLEXIBLE SUBSTRATE. SUBSTRATE IS MOUNTED ON DOUBLE ROLLERS TO MINIMIZE POSSIBLE DAMAGE OF TIGHTLY PACKED SINGLE ROLLER.
17. ROLLED SUBSTRATE 2'x4' SUBSTRATE IS ROLLED ON DRUM DEPLOYED BY CENTRIFUGAL FORCE & RIGIDIZED BY SEGMENTED BEAMS	SHEET ALUMINUM SEGMENTED BEAMS AND FRAME.	BEAM WIRE TENSIONING DEVICE BY NEGATOR SPRING. DEPLOYING REELS & MOTOR.	1x2 CELL WOULD BE MOUNTED ON BOTH SIDES OF FLEX SUBSTRATE.	CARE WOULD BE REQUIRED IN HANDLING BEAMS & SUBSTRATE PARTICULARLY DURING PACKING.	SUBSTRATE IS WOUND ON A SINGLE ROLL, RESTRAINED BY A PAY-OUT RIBBON. USING MODIFIED PACKAGING DIMS, FITS WITHOUT DIFFICULTY.	DEPLOYING REELS PAY OUT RIBBON & ALLOW SUBSTRATE TO UNWIND BY CENTRIFUGAL FORCE. BEAMS ARE RIGIDISED BY TAKING UP SLACK IN BEAM WIRES.	THE SEGMENTED BEAMS BECOME RIGID ON DEPLOYMENT & WIRES ARE LOCKED. TRANSVERSE STIFFENER RODS ARE BONDED IN SUBSTRATE.	BUFFER PADS WOULD BE REQUIRED TO PREVENT VIBRATION DURING LAUNCH.	RELATIVELY SIMPLE MECHANICAL DEVICES. DOUBLE SIDED SUBSTRATE WOUND ON SINGLE ROLL. NO PROTECTIVE MAT OR WINDING DRUM.	COULD BE EASILY ADAPTED TO LARGER ARRAYS BY USE OF DEEPER SEGMENTED BEAMS.	VERY GOOD. DEPLOYMENT WOULD BE CONSTANT & AUTOMATIC. SIMPLE MECHANISMS.		THIS CONCEPT WOULD REQUIRE A MODIFIED PACKAGING SIZE BASED ON DIFFERENT LOCATION OF PANELS WITHIN SAME VEHICLE ENVELOPE (SEE DWG.) PROBABLY THE BEST APPROACH TO A FLEXIBLE SUBSTRATE WITH SEGMENTED BEAM STIFFENING.

Figure 1. Concept Evaluation Chart

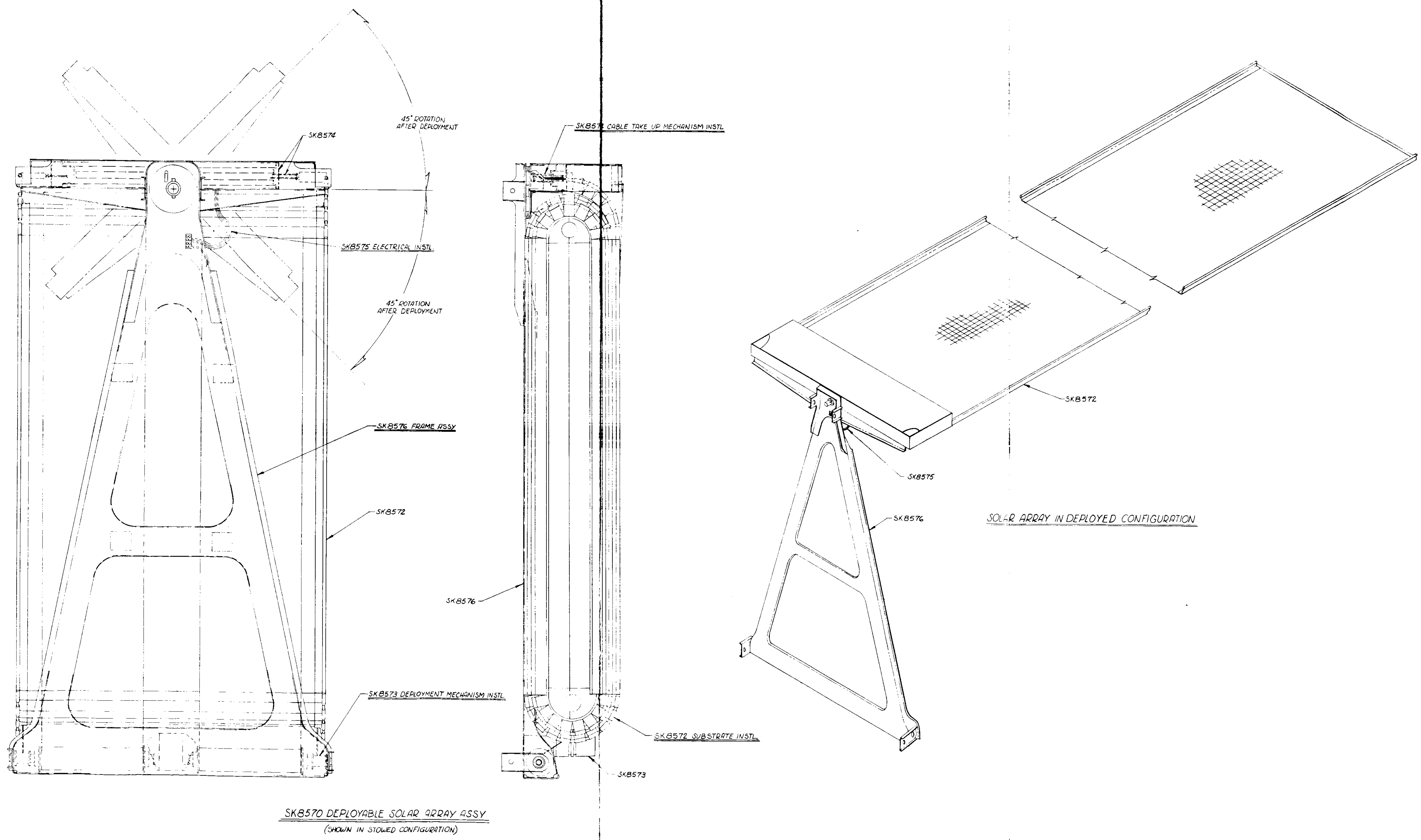


Figure 2. Assembly - Deployable Solar Array

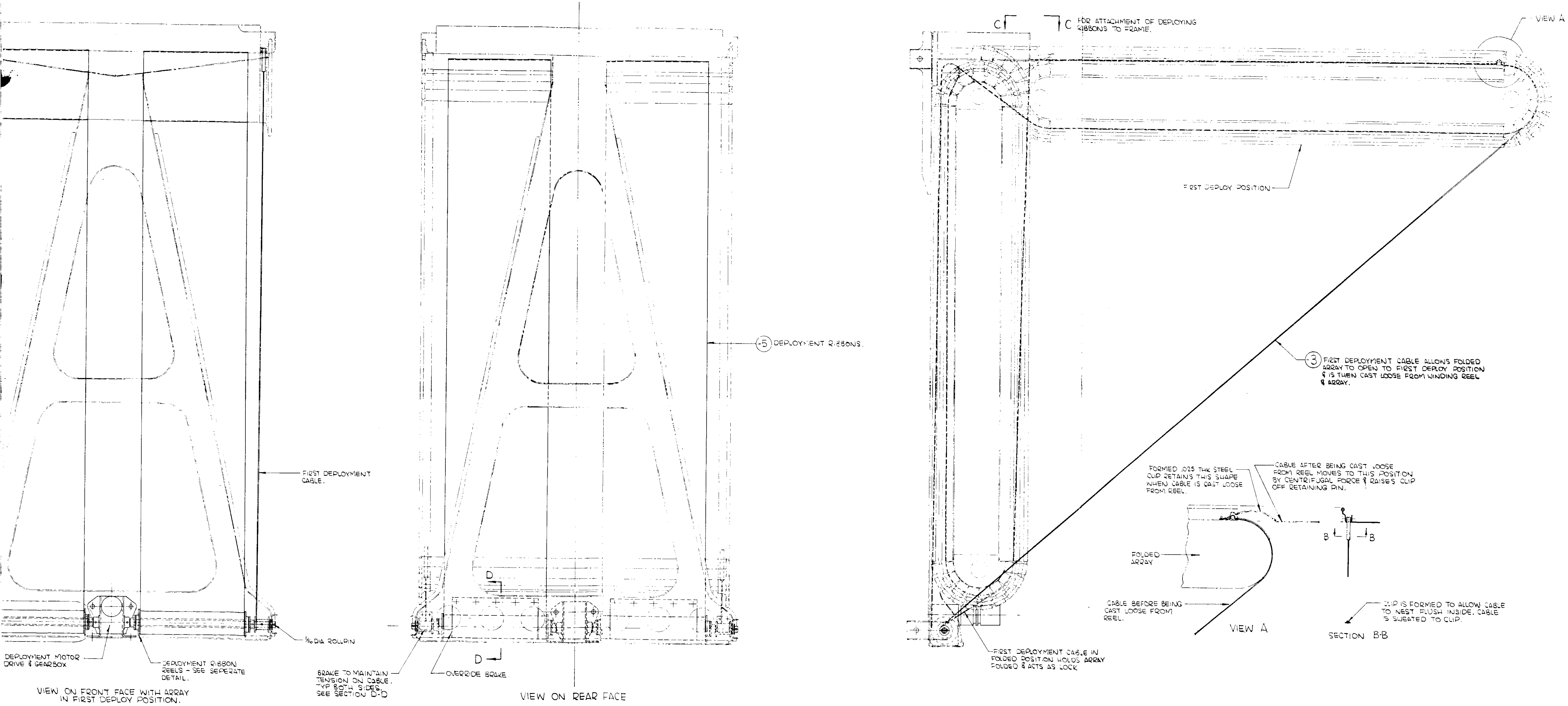
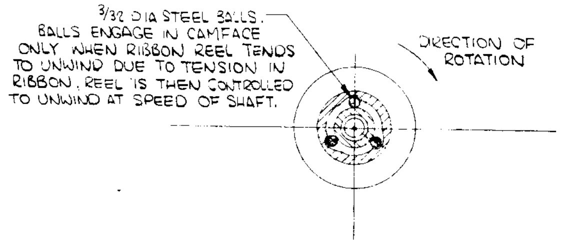
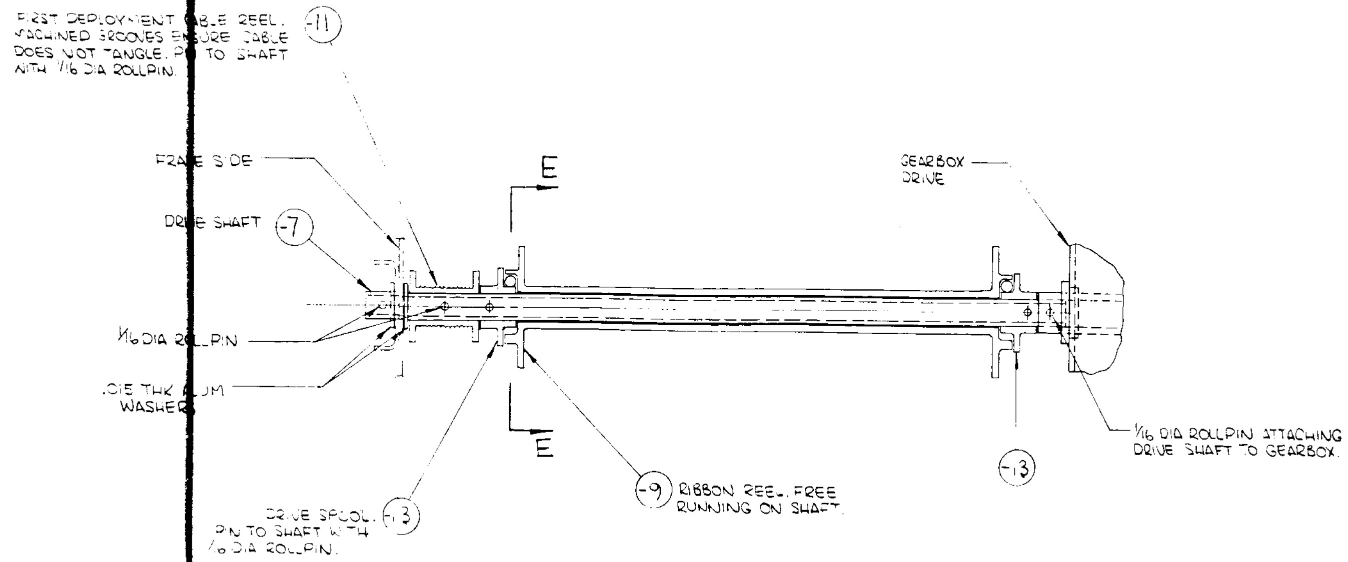


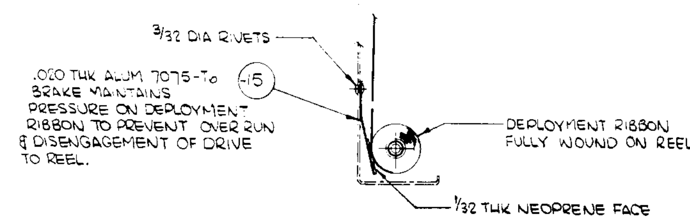
Figure 5. Deployment Mechanical Installation



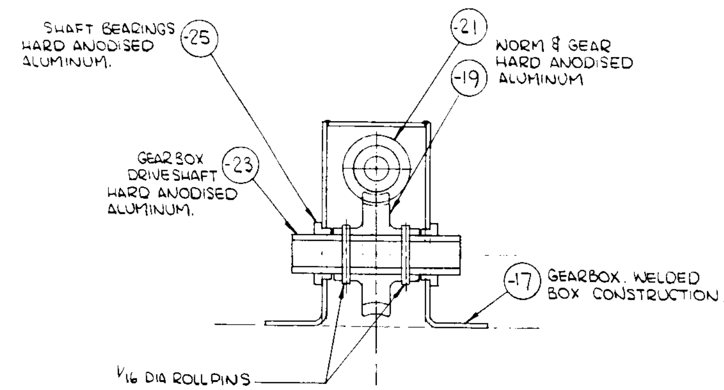
SECTION E-E
DETAIL OF OVERRIDE CLUTCH



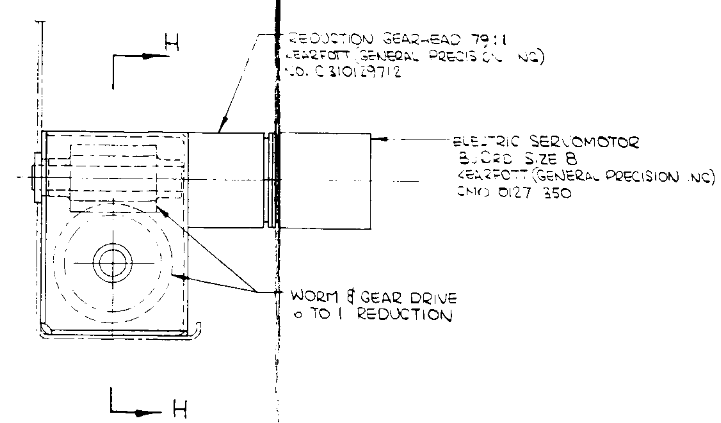
DETAIL F SCALE : 2/1



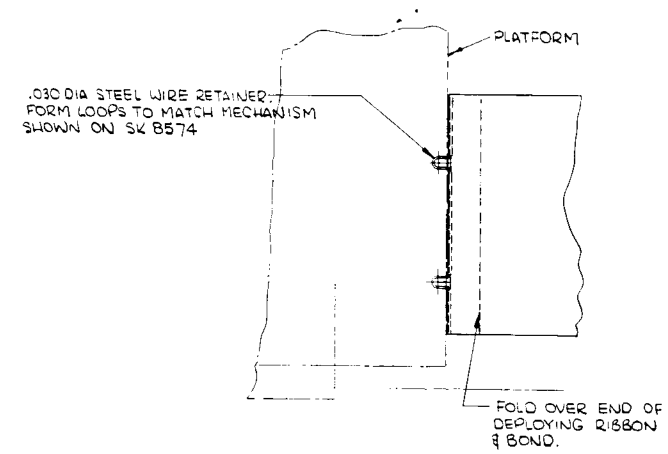
SECTION D-D
METHOD OF BRAKING CABLE REELS SIMILAR.



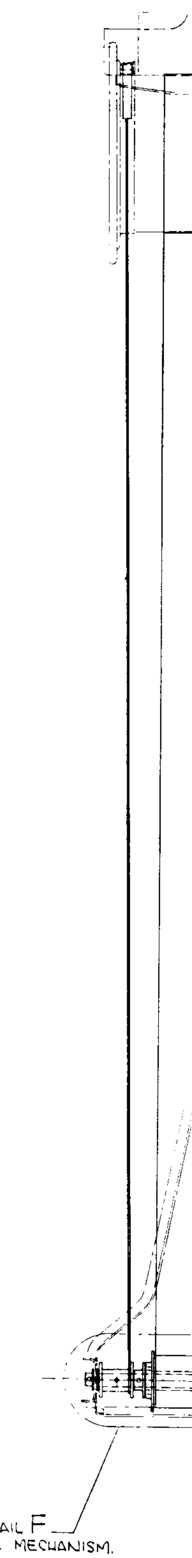
SECTION H-H SCALE: 2/1



DETAIL G SCALE : 2/1



VIEW C-C



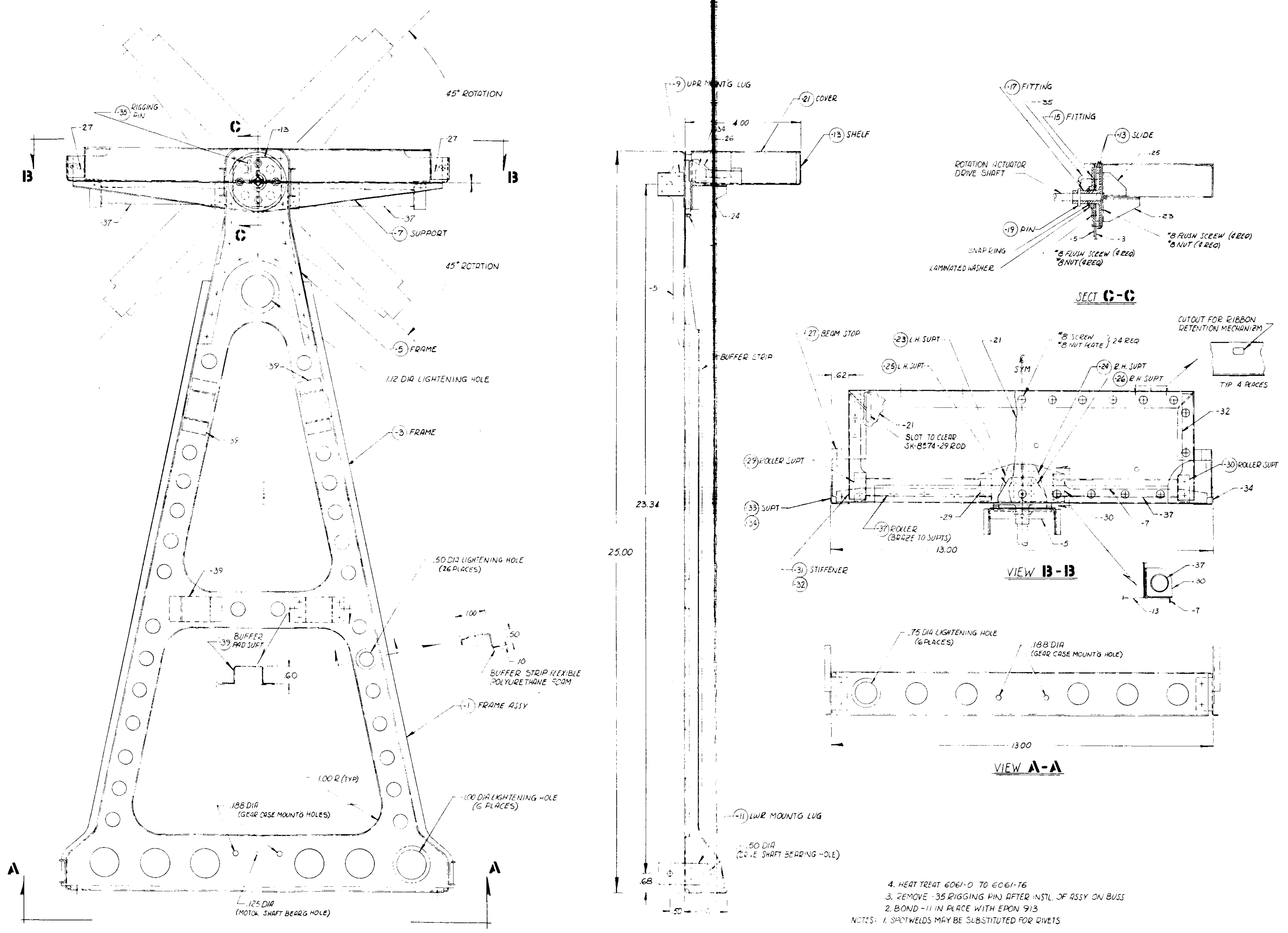


Figure 4. Frame Assembly - Tilting Head

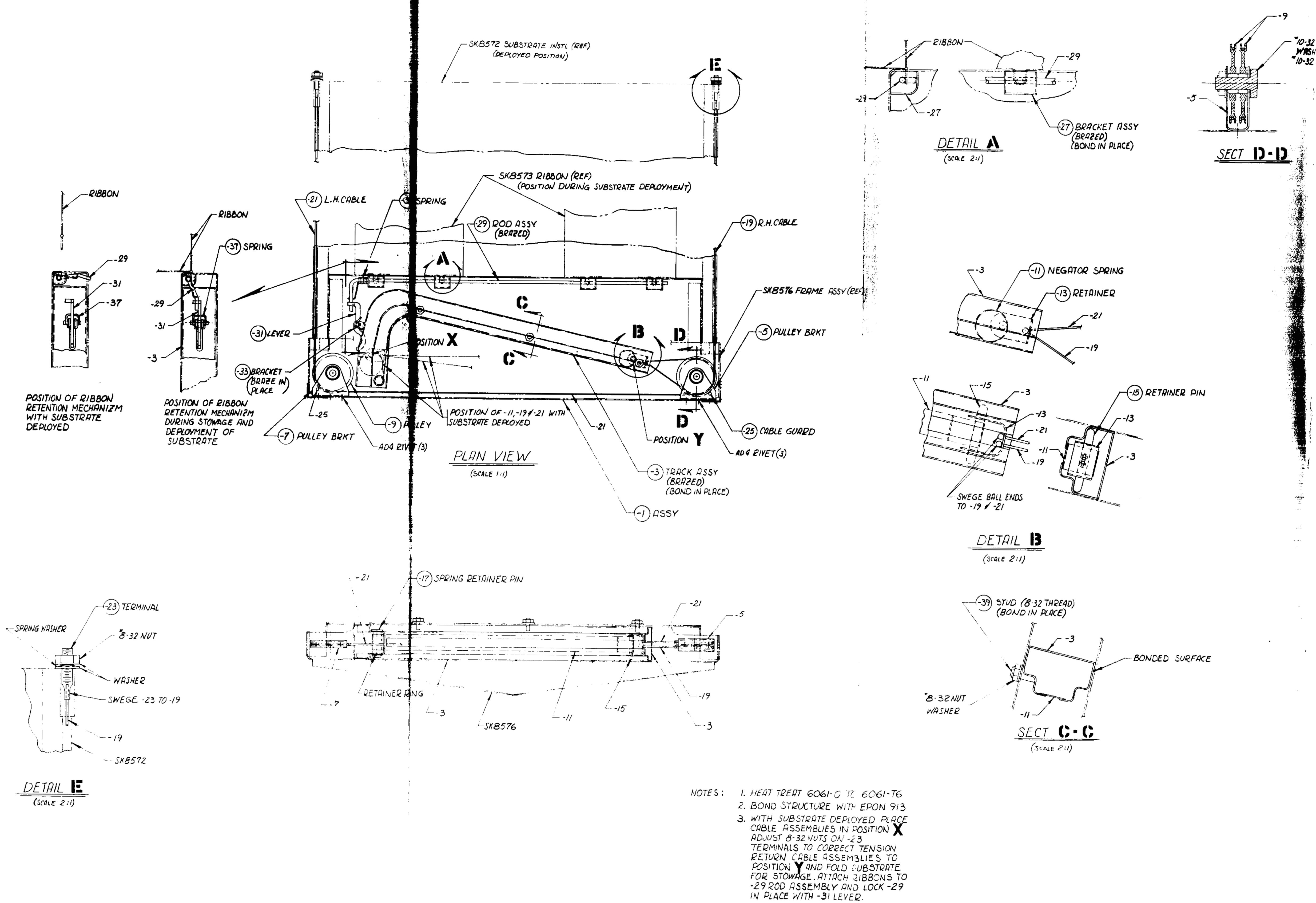


Figure 6. Cable Take-Up Mechanism

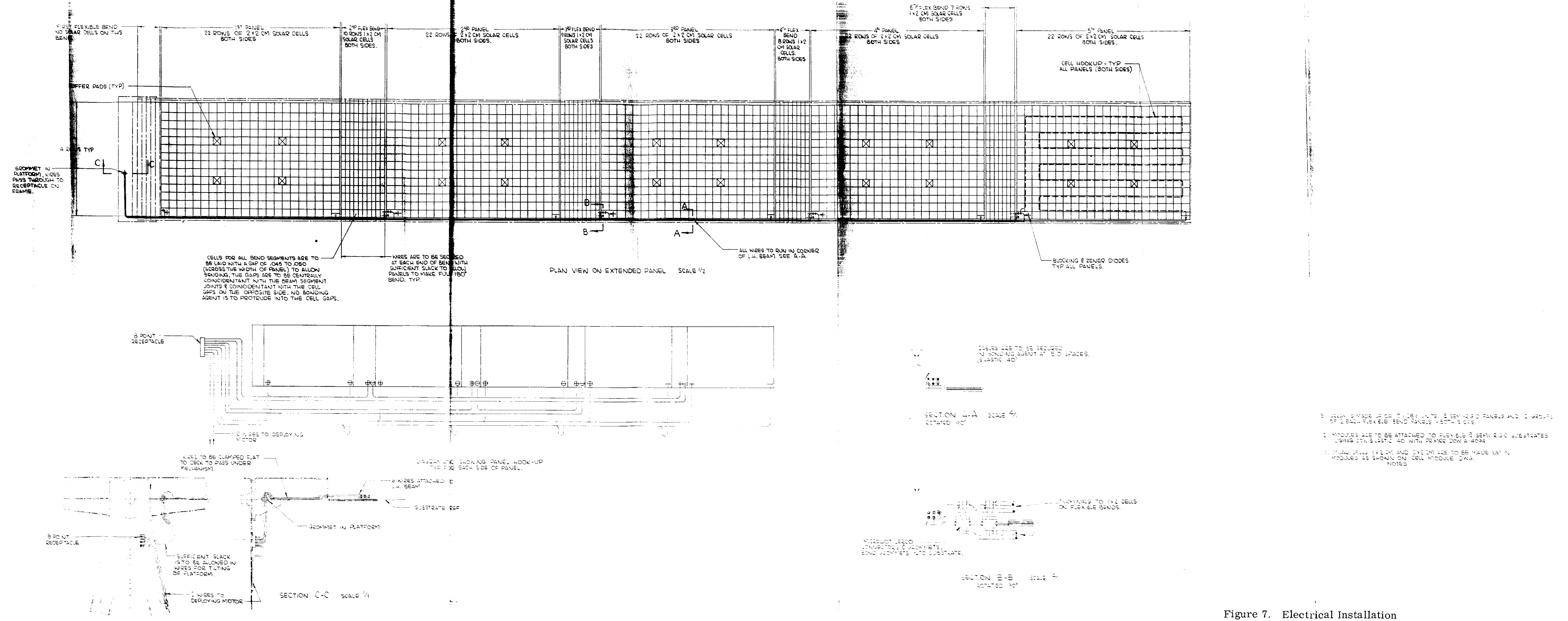
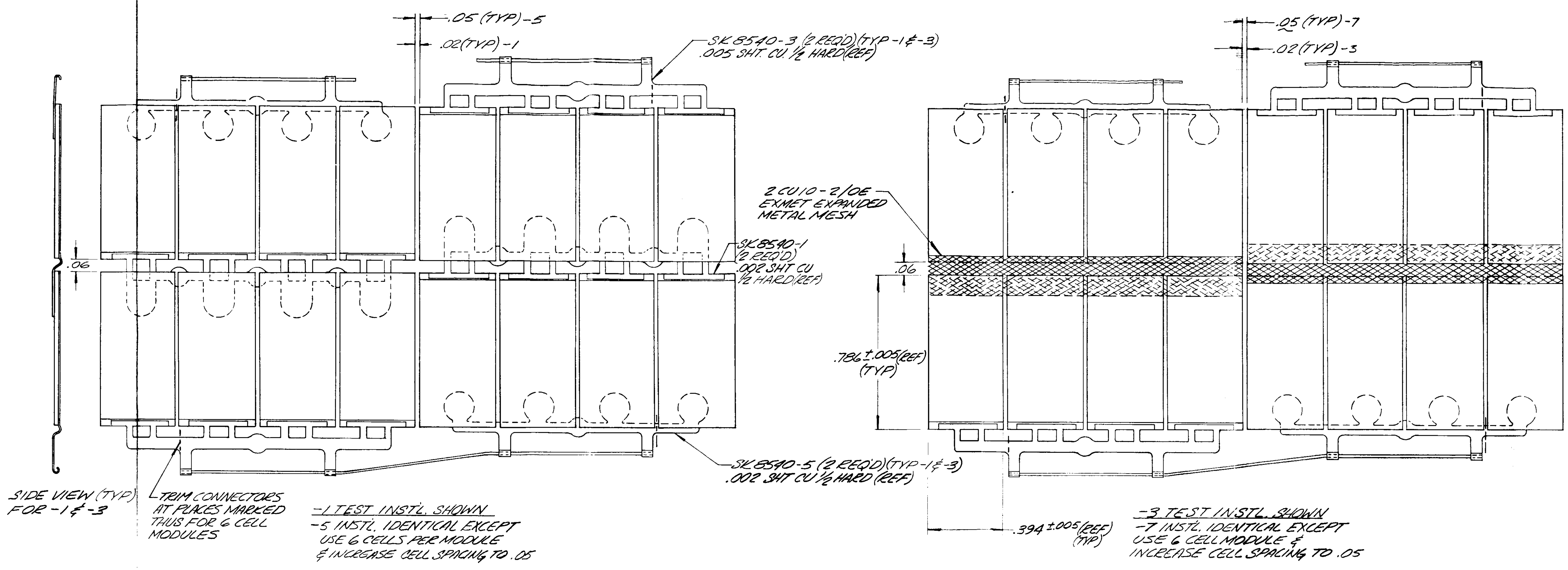


Figure 7. Electrical Installation



NOTES:
1. ATTACH FILTER GLASS WITH DOW SYLGARD 182
2. LOCATE & INSTALL -1 & -3 PER RYAN TEST PROCEDURE FOR GODDARD SOLAR PANELS

Figure 8. Solar Cell Module

recoiled across a flat surface. A hollow guide track is used to provide this surface and the spring attached to one end is uncoiled through the track to attach to the cables at the other end. As the array unfolds, slack is thus taken up by the constant load of the negator spring recoiling within the guide. When the array is fully extended, the negator spring has reached a position at which a change in direction occurs. A bend in the guide track causes the spring, in effect, to climb an inclined plane with reference to the cable pivot points and thus, by using the same constant load of the spring, an increased tension results in the cables and provides the required load for rigidizing the segmented beams. To prevent a bending load in the beams from pulling the spring back down the inclined plane, a slight reverse slope in the track is provided to lock the mechanism.

Before the negator spring reaches the final position and locks in place, the spring trips a trigger latch which disconnects the deployment ribbons (Ref. Fig. 6-31) and activates a microswitch (not shown) which disconnects the motor.

3.4.3 Technical Analysis

3.4.3.1 Weight Breakdown (Summary)

Item	Ryan Drawing No.	Calculated Weight, lbs.
Substrate assembly	SK-8572	1.79
Installed solar cells (1x2 cm x .018" thick) with Dow silastic 140 solar cell adhesive, Dow Corning Sylgard 182 filter adhesive, and .006 in. thick filters.	SK-8563-7	6.97*
Deployment mechanism installation	SK-8573	0.78
Cable takeup mechanism	SK-8574	0.25
Electrical installation	SK-8575	0.16
Frame assembly	SK-8576	0.83
Total		10.78

* Based on 16.6 $ft.^2$ of net area. This is the summation of actual detailed weight figures (see Section 4.5).

If thinner solar cells are used (approximately 40% less solar cell weight), the above total weight could possible be reduced to 9.36 lbs.

Detailed Weight Breakdown

1	SK 8570 Deployable solar array			10.78 lbs
	1 SK 8572 Substrate assy			
	1 SK 8572-1 Substrate assy		1.79	
	5 - 3 Flex. substrate	.0199		
	5 - 5 Semi-rigid substrate	.1144		
	2 - 7 Beam & beam segments	.3141		
	2 - 9 Beam cap tube	.0753		
	1 - 11 End stiffener	.0473		
	9 - 13 Cross stiffener	.0043		
	18 - 15 Buffer pads	.00025		
	10 - 17 Reinf. strips	.00045		
	1 - Folding core	.1363		
	3 - Bend pad	.0080		
	Adhesive	.0853		
	1 SK 8573 Deployment mech. installation			.78 lbs
	2 - 3 Cable	.0054		
	2 - 5 Deployment ribbon	.2040		
	2 - 7 Drive shaft	.0093		
	2 - 9 Ribbon reel	.0244		
	2 - 11 Cable reel	.0032		
	4 - 13 Drive spool	.0020		
	2 - 15 Brake	.0208		
	1 - 17 Gearbox	.0428		
	1 - 19 Gear	.0241		
	1 - 21 Wormgear	.0326		
	1 - 23 Shaft	.0085		
	2 - 25 Bearing	.0017		
	1 Motor	.0625		
	1 Reducing Gearhead	.0625		
	1 SK 8576-1 Frame assy			.83 lbs
	1 - 3 Frame	.3670		
	1 - 5 Frame	.0710		
	1 - 7 Support	.0680		
	2 - 9 Upr mtg lug	.0034		
	2 - 11 Lwr mtg lug	.0050		
	2 - 13 Slide	.0054		
	1 - 15 Fitting	.0296		

1 - 17 Ftg	.0270	
1 - 19 Pin	.0027	
1 - 21 Cover	.0810	
1 - 23 LH support	.0050	
1 - 24 RH support	.0050	
1 - 25 LH support	.0031	
1 - 26 RH support	.0031	
2 - 27 Beam stop	.0050	
1 - 29 Roller support	.0029	
1 - 30 Roller support	.0029	
1 - 31 Stiffener	.0470	
1 - 32 Stiffener	.0470	
1 - 33 Support	.0027	
1 - 34 Support	.0027	
1 - 35 Rigging pin	Removed	
2 - 37 Rollers	.0190	
4 - 39 Buffer pad supports	.0008	
Rivets	Incorp.	
Adhesive	Negl.	
Screws & nuts	.0007	

1 SK 8574-1 Assembly		.25
1 - 3 Track assy	.0829	
1 - 5 Pulley brkt	.0062	
1 - 7 Pulley brkt	.0058	
3 - 9 Pulley	.0103	
1 - 11 Negator spring	.0291	
1 - 13 Retainer	.0016	
1 - 15 Retainer pin	.0012	
1 - 17 Spring pin	.0012	
1 - 19 RH cable	.0163	
1 - 21 LH cable	.0180	
2 - 23 Terminal	.0059	
2 - 25 Cable guard	.0002	
4 - 27 Brkt assy	.0019	
1 - 29 Rod assy	.0087	
1 - 31 Lever	.0026	
1 - 33 Brkt	.0011	
1 - 35 Spring	.0002	
1 - 37 Spring	.0001	
3 - 39 Stud	.0059	
2 Springwasher	.0001	
11 Washers	.0001	

7	Nuts	.0001	
1	Retainer Ring	.0001	
6	Rivets	Negl.	
1	SK 8575 Electrical instl		.16 lbs
1	8 point receptacle	.0400	
1	Grommet	.0001	
	Wire 100'	.0192	
5	Zener diode	.0200	
36	Connectors & grommets	.0001	
	SK8563-7 Installation (solar cell)		6.97 lbs

3.4.3.2 Dynamic Considerations

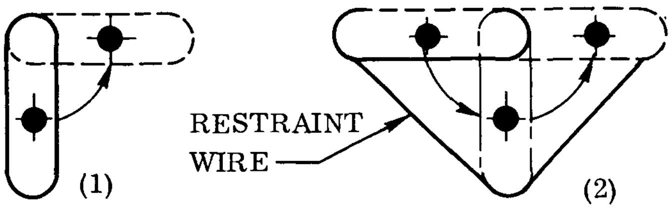
The two areas of concern from a dynamics viewpoint are: (1) Launch vibration environment and (2) deployment during the spin condition.

Preliminary investigations show that the array is satisfactory to withstand both sinusoidal and white Gaussian noise environments. This conclusion is based on the wide use of padding material in the stored configuration, restricting movement and inertia forces associated with such movement, to negligible values. It is the low end of the white noise band input (11.5 g rms from 20-2K cps is specified) that is critical. The low end of the sinusoidal input is only slightly less critical.

Again, preliminary investigations show that no undesirable motion or loading conditions should arise during deployment in the spin condition, provided reasonably slow deployment rates are used. The critical deployment time is 1.35 second for complete deployment at 160 rpm spin rate, based on Coriolis force generation (a tangential force), which would place compression in the trailing edge of the array, causing a severe buckling condition. Practical deployment rates (under control of restraint wires) would certainly be greater than 1.35 second, thus, no difficulties from Coriolis forces are anticipated. The large centrifugal forces generated (from 0 at the tip to 660 pounds at the root in the fully deployed configuration at 160 rpm) are a considerable stabilizing force, as they are in helicopter blades in flight. These blades, as is the array, are extremely flexible and are stable in the presence of large centrifugal forces, even under severe lateral and torsional loadings (which do not apply in the present case).

Local motion during deployment in the spin condition was also studied. At first, it was felt that raising and lowering (if the spin axis is considered "vertical") the local cg of elements of the array during deployment might cause some whipping. This proved not to be a problem, since in all cases, the centrifugal force on the elements provides tension components that far override normal-to-plane inertia forces. The deformation from a neutral position of all elements during deployment is negligible (on the order 10^{-2} inches).

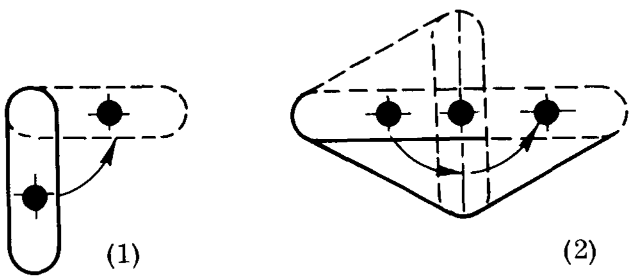
It should be noted, that the deployment-time-position history during fold-out cycling is not as depicted in layouts showing the following sequence:



Note that cg lowers and raises as depicted -- the array does not do this.

Rather, the fold-out sequence is such as to maintain a constant vertical position of the total cg during all phases of deployment.

Centrifugal force provides the cg alignment, except for the first 90° rotation of the rigid package. The correct deployment sequence is shown below:



Note that cg maintains position vertically during deployment. Surface of array moves up and down locally during fold-out.

It is true that cg shift (raising) in the stored configuration occurs during the first 90° of fold-out. In space, the cg follows a helical path. Centrifugal forces during this phase of the deployment place normal-to-plane asymmetrical loads on the package as it reaches different positions in the spin cycle. (It is these loads that, in the flexible configuration, might cause whipping if cg raising and lowering were permitted, e.g., if the entire array were accelerated longitudinally along the spin axis.) Studies show that cg shift in the stored configuration imposes small problems. A ±10% of steady state design loads at the frame attachments is anticipated, due to cg whipping, a mild result. Fifteen seconds total deployment time was assumed in this part of the study. The motion during this phase of the deployment should be quite satisfactory.

3.4.3.3 Loads Analysis

Included in this section are substrate in-plane load curves for two different deployment conditions. The curve based on a constant 160 rpm spin rate during deployment is used for comparison only. The curve based on a reducing spin rate from 160 to 40 rpm during deployment was a design requirement and is used as such.

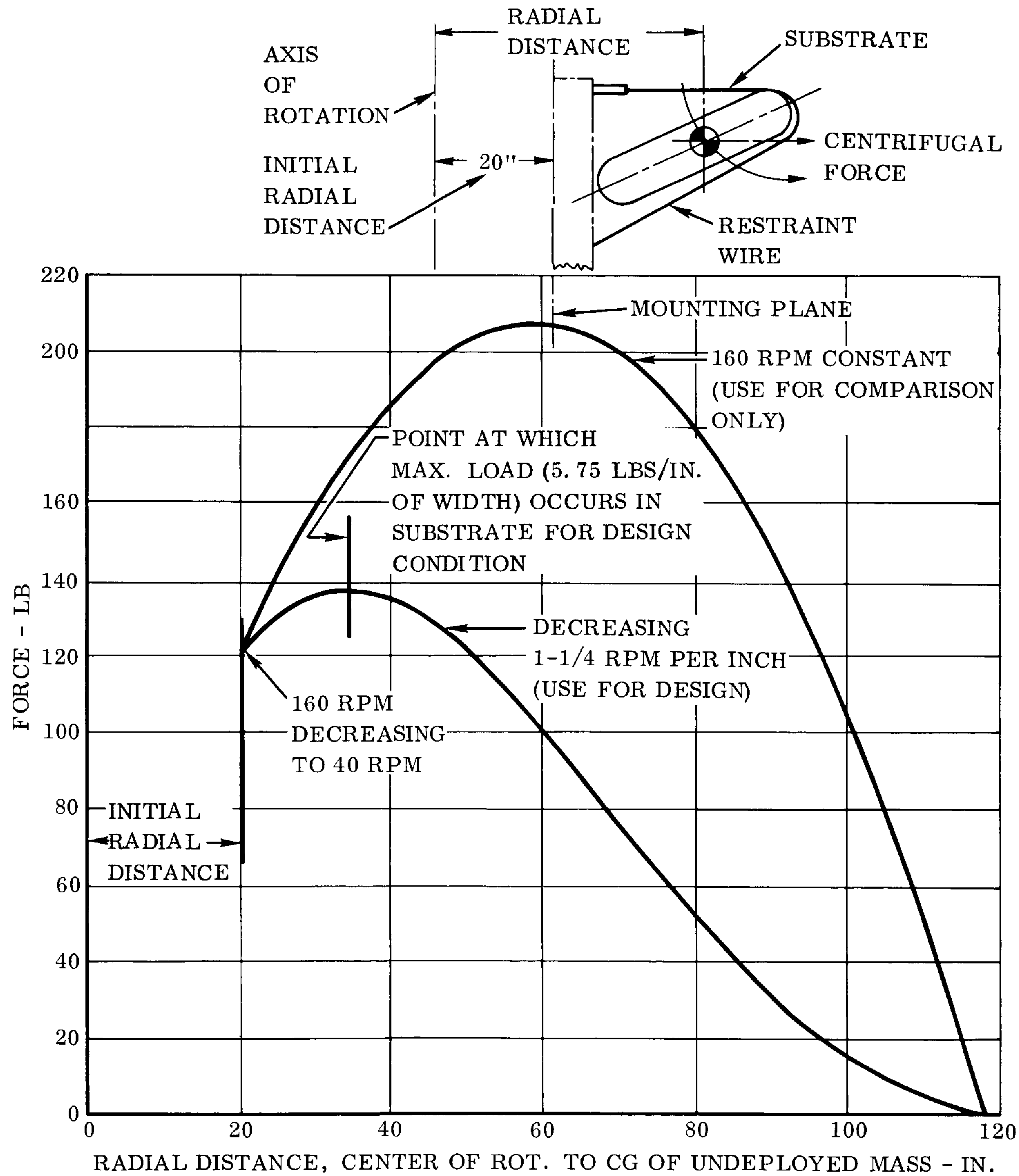


Figure 9. Solar Array Load Diagram

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4.0 MATERIALS INVESTIGATION

4.1 BASIS FOR MATERIAL SELECTION (ENVIRONMENT)

Materials given consideration were based on environment presented in paragraph 3.1.

4.2 INVESTIGATION OF ONE PIECE SUBSTRATES WITH SEMI-RIGID AND FLEXIBLE AREAS

The following investigation was made to determine a method of fabricating a one piece semi-rigid solar cell substrate which would have intermittent flexible areas. The idea is directly applicable to the segmented beam design concept, where large flat substrate areas exist in the packaged configuration with short flexible areas required for packaging. The semi-rigid substrate provides in-plane shear capability of the deployed substrate.

The specimens shown in Figure 10 were fabricated by three different methods. Method procedures and results are:

Method A - Coat Semi-Rigid Areas First

Material Investigated -

RP7A-828 resin for semi-rigid areas

Procedure -

a. Flexible area masked only
b. Resin coating added, vacuum bagged, squeegeed, cured

Result -

Undesired wicking of RP7A-828 into 100% of flexible area, producing an unwanted brittle condition.

Method B - Treat and Mask Flexible Area Before Coating Semi-Rigid Areas

Material Investigated -

RP7A-828 resin for semi-rigid areas

Procedure -

a. Flexible area treated with Methocell and then masked.
b. Resin coating added, vacuum bagged, squeegeed, cured
c. Maskant removed and Methocell treated area cleaned.

Result -

Wicking of RP7A-828 into flexible area. Unable to remove all of RP7A-828 resin from flexible area, producing an unwanted brittle condition.

Method C - Coat Flexible Areas First

Materials Investigated -

Area 2 - RTV 30 primed with Dow A-4094 silicone
Area 4 - LTV 602 primed with Dow A-4094 silicone
Area 6 - LTV 615 primed with General Electric SS4120 silicone.

Procedure -

a. Semi-rigid areas 1, 3, 5, and 7 masked only.
b. After priming and air drying 1 hour, coatings added, vacuum bagged, squeegeed, cured.

Result -

Undesired wicking of all but RTV 30 into semi-rigid areas, producing an unbondable condition for a semi-rigid coating.

Conclusions

The best method of providing a one piece semi-rigid substrate with intermittent flexible areas is to first apply and cure resin for the flexible areas. A viscous type resin in the uncured state, such as RTV 30 or 40 silicone, is required to prevent wicking into unwanted areas. The semi-rigid areas are then produced by coating the desired areas with an RP7A-828 epoxy resin. Both of the above mentioned resins have characteristics approved for space applications, i.e., low outgassing, negligible weight loss and radiation effects.

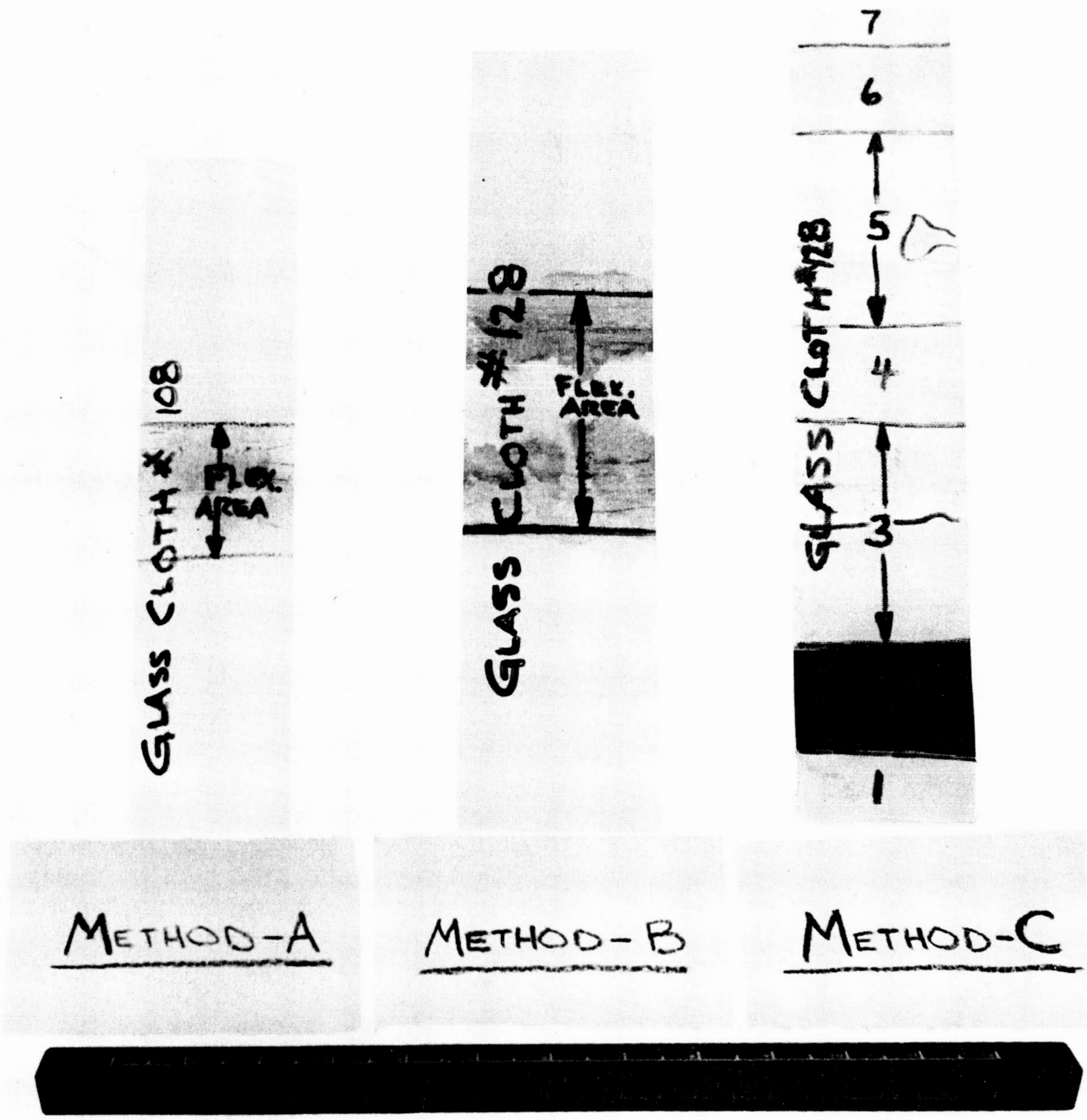

Figure 10. Substrate - Material Specimens

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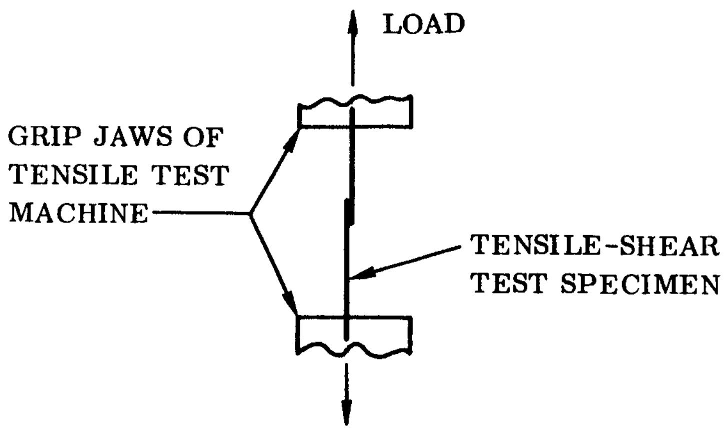
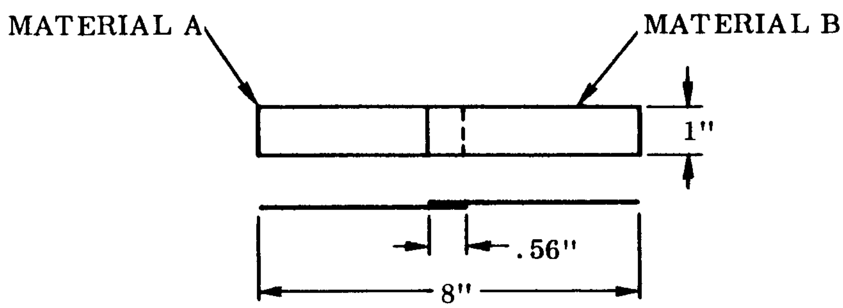
4.3 INVESTIGATION OF SUBSTRATE LAP SPLICES

Test Set-Up



Test Specimens

Fabricate per the following:



Specimen No.	Material A	Material B	Shear Lap Adhesive
TS-1 thru TS-3	Armalon 403-108 (Teflon coated glass cloth)	128 Glass cloth impregnated with RP7A-828 epoxy resin	RTV 40 (PRC 1902 primer)
TS-4 thru TS-6			Dow silastic 140 (Dow A-4094 primer)
TS-7 thru TS-9			RTV 615 (General Electric SS-4120 primer)

Specimen No.	Material A	Material B	Shear Lap Adhesive
TS-10 thru TS-12	108 glass cloth coated with RM-5 white silicone rubber (3 M Co.)	128 glass cloth impregnated with RP7A-828 epoxy resin	RTV 40 (PRC 1902 primer)
TS-13 thru TS-15			Dow silastic 140 (Dow A-4094 primer)
TS-16 thru TS-18			RTV 615 (General Electric SS-4120 primer)
TS-19 thru TS-21	Armalon 403-108 (Teflon coated glass cloth)		RTV 40 (Dow A-4094 primer)
TS-22 thru TS-24			
TS-25 thru TS-27	108 glass cloth coated with RM-5 white silicone rubber (3 M Co.)		RTV 40 (PRC 1901 primer)

Notes:
1. All Armalon to be etched in Ryan Lab, prior to bonding.
2. Do not prime silicone material.
3. All specimens to be cleaned with MEK prior to bonding.

Test Objective

The objective of this test is to show capability of a substrate lap splice to transfer in-plane loads induced during deployment. The splice overlap dimension is based on the segmented beam concept (Ref. Ryan Drawing No. SK 8572). Various substrate materials and silicone splice adhesives are investigated.

Although tests are conducted at room temperature, conditions are considered to be simulated since the silicone bonding adhesives have little deviation in mechanical properties between the temperature extremes (-94° F to +158° F) possible during deployment.

The specimens also serve as preliminary investigation in adhesive bonding to Teflon, silicone and epoxy coated glass cloth. This is useful for adhesive materials selection and application procedures for solar cell bonds.

Test Procedure

Pull specimens to failure in a Tinius Olsen Test Machine. Apply load at a slow rate at room temperature. Record type of failure, ultimate load, and bond rating (poor, good, excellent). The bond rating will be based on ability to peel Armalon or silicone coated fabric from epoxy coated fabric at joint using the fingernail, thumb and index finger.

Test Results

Specimen No.	Ultimate Load, lbs.		Type Failure Under Tensile Shear Load	Bond Rating (Resistance to peel)
	Minimum	Average		
TS-1 thru TS-3	38	41	Armalon fabric	Good
TS-4 thru TS-6	43	49	Armalon fabric	Excellent
TS-7 thru TS-9	39	44	Armalon fabric or Armalon fabric to adhesive	Poor
TS-10 thru TS-12	43	71	Silicone coated fabric	Excellent
TS-13 thru TS-15	58	73	Silicone coated fabric or fabric to adhesive	Good
TS-16 thru TS-18	9	15	Silicone coated fabric to adhesive	Poor
TS-19 thru TS-21	49	58	Armalon fabric	Poor
TS-22 thru TS-24	37	44	Armalon fabric	Good
TS-25 thru TS-27	50	54	Silicone coated fabric	Good

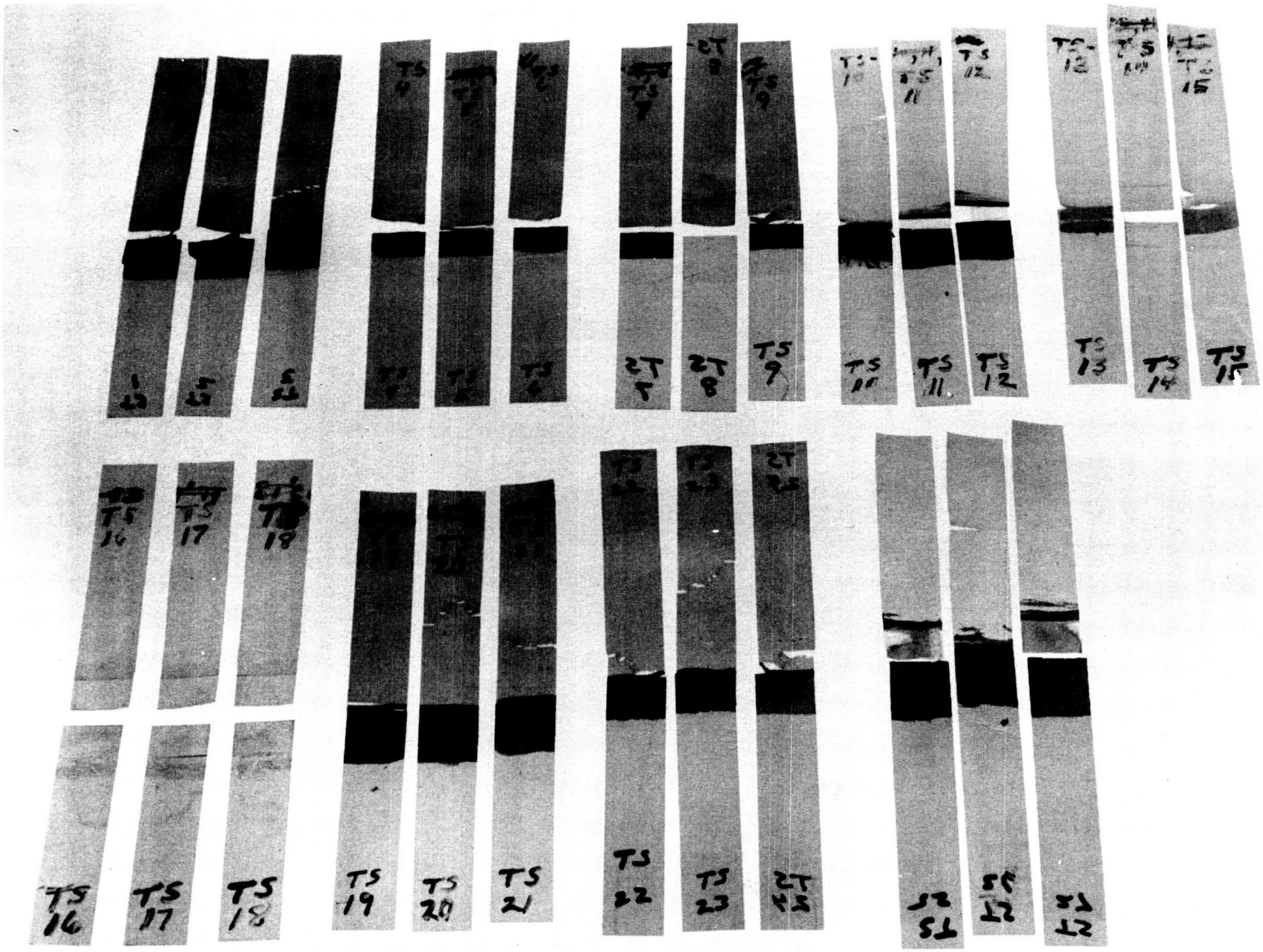


Figure 11. Substrate - Splice Test Specimens After Test

Conclusions

Tensile-shear test results show that any of the materials and adhesive tested have the capability of carrying in excess of the maximum 5.75 lbs/in/width in-place substrate load (see Fig. 9, Section 3.4.3.3).

Peel tests show that only two adhesive and primer combinations tested with Teflon coated fabric merit further investigation for attaching solar cells.

1. RTV 40 (catalyzed with thermolite 12) with PRC 1902 primer.

2. Dow Silastic 140 with Dow A-4094 primer.

Three adhesive and primer combinations tested with silicone coated fabric have ratings which merit further investigation for attaching solar cells. The RTV 40 adhesive and PRC-1902 primer combination will not be considered because of its blue color. The following will be further investigated:

1. RTV 40 (catalyzed with thermolite 12) with PRC 1901 primer.

2. Dow Silastic 140 with Dow A-4094 primer.

4.4 INVESTIGATION OF ADHESIVE BONDING SOLAR CELLS TO TEFLON COATED GLASS CLOTH

Test Objective

The objective is to further investigate the RTV 40 silicone adhesive for bonding solar cells to Teflon coated glass cloth. This is a logical extension of work presented in Section 4.3.

Various primers and Teflon cleaning processes are investigaged at room temperature to give relative comparisons of bond cleavage strength. Solar cells undergo the following cleaning process prior to priming.

1. Methyl alcohol

2. Deionized water

3. Acetone

4. Deionized water

5. Vythem

Test Procedure

Break bond between teflon coated glass cloth and solar cell by a prying action using a load test indicator. Rate bond strength relative to cleavage load indicated.

Test Results

Specimen No.	Primer	Teflon Cleaning Process Prior to Priming	Bond Rating (Resistance to Cleavage)
1	PRC 1901	Iso-propyl alcohol	Poor
2	PRC 1902		Excellent
3	A-4094		Good
4	PRC 1901	1. Iso-propyl alcohol	Poor
5	PRC 1902	2. Vythem	Excellent
6	A-4094		Excellent

Specimen No.	Primer	Teflon Cleaning Process Prior to Priming	Bond Rating (Resistance to Cleavage)
7	PRC 1901	1. Iso-propyl alcohol	Good
8	PRC 1902	2. Ether	Excellent
9	A-4094		Poor
10	PRC 1901	1. Iso-propyl alcohol	Fair
11	PRC 1902	2. Ether	Fair
12	A-4094	3. Vythem	Fair

Conclusions

Test results show that the greater percentage of excellent bonds occur when PRC 1902 primer is used for bonding solar cells to Teflon coated glass cloth using RTV 40 silicone adhesive.

The following observations were noted concerning cleaning processes. It is suggested that they be considered only as guides and not conclusive evidence based on the few number of specimens tested:

1. When using PRC 1901 primer, bond rating tends to upgrade with subsequent cleaning prior to priming.

2. When using PRC 1902 primer, bond rating tends not be affected with subsequent cleaning prior to priming.

3. When using A-4094 primer, bond rating tends to increase with subsequent cleaning prior to priming. The exception is with the use of ether, which tends to downgrade bond rating.

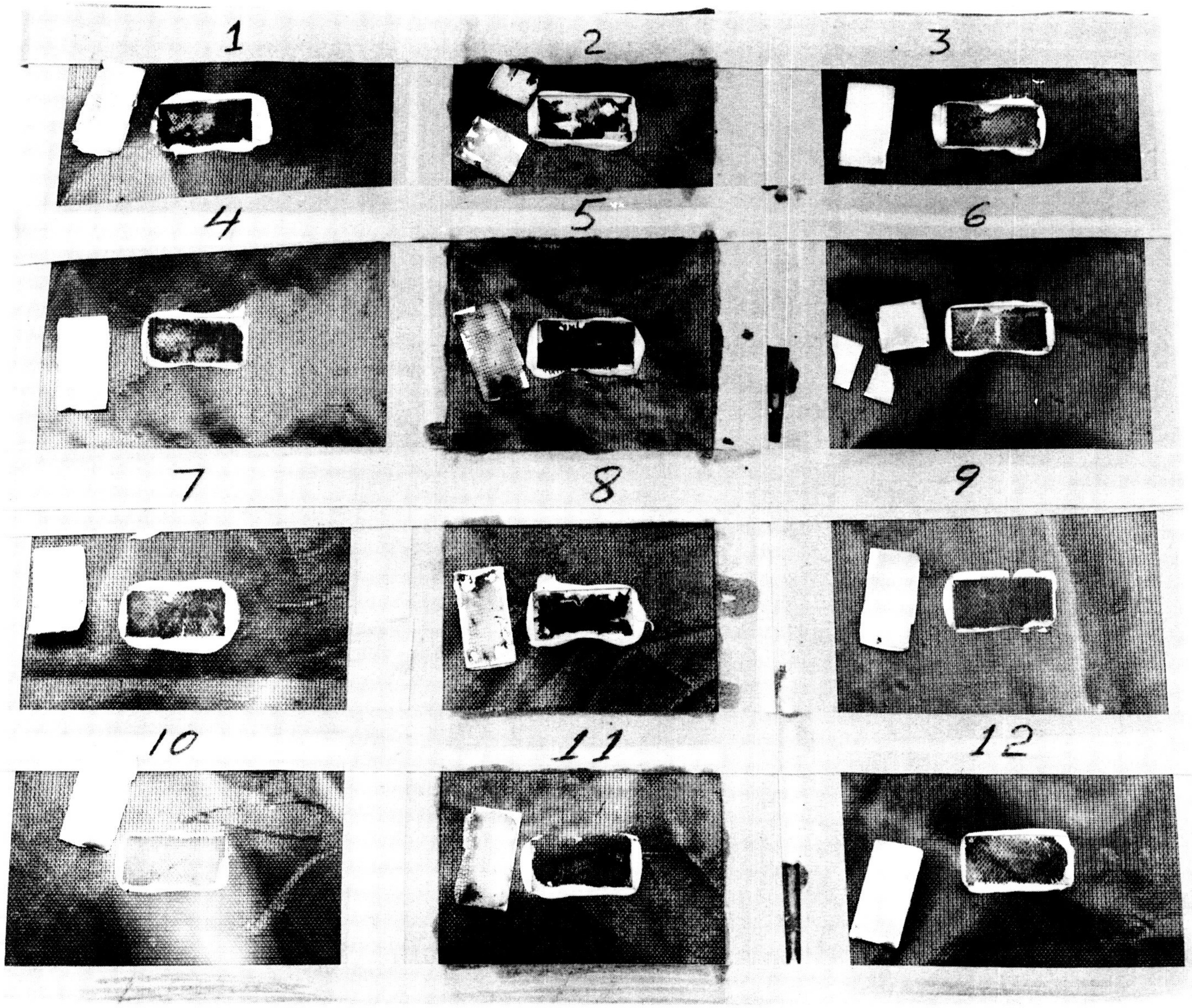


Figure 12. Solar Cell Bond Test Specimens After Test

4.5 WEIGHT BREAKDOWN FOR VARIOUS APPLICABLE SUBSTRATE MATERIALS, ADHESIVES, AND ATTACHED ELECTRICAL ITEMS

The following are actual weights of samples checked:

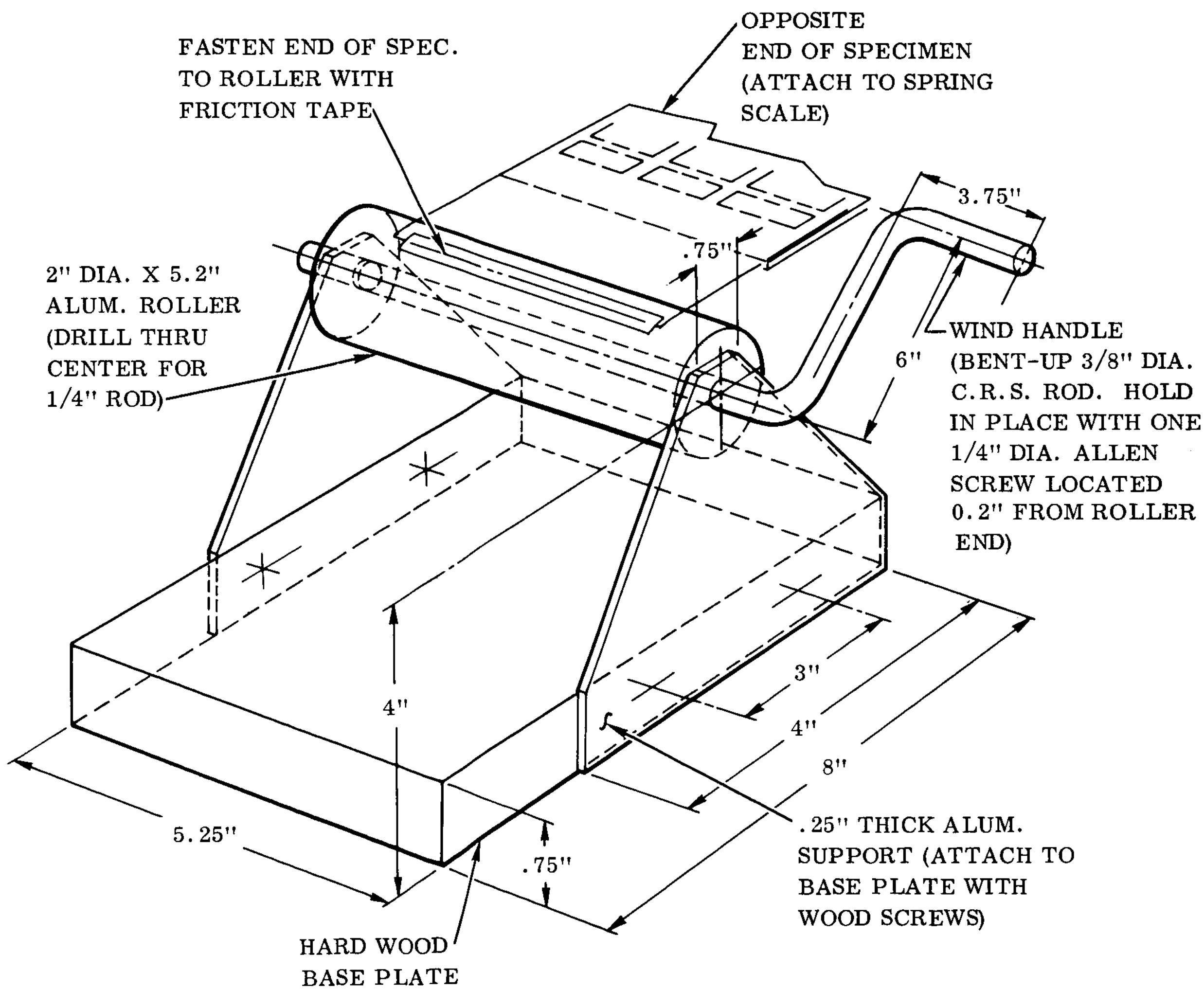
Item	Weight, lbs/ft^2 of Substrate Area
Substrate Material	
Etched Armalon 403-108 (Teflon coated 108 glass cloth .0035" thick)	0.032
Etched Armalon 405-112 (Teflon coated 112 glass cloth .005" thick)	0.054
3M Company RMS-108 (Silicone coated 108 glass cloth .0045" thick)	0.036
RP7A-828-128 (Epoxy impregnated 128 glass cloth .0085" thick)	0.071
Solar cell modules less filter glass (utilizing 1 x 2 cm x .018" thick Ponn solar cells with OHMIC strip on one cm dimension)	
Ref. Ryan Drawg SK-8563-5	0.226
Ref. Ryan Drawg SK-8563-7	0.230
Solar cell module adhesives	
RTV40 (catalyzed with thermolite 12) with 1901 or 1902 primer	0.075
Dow Silastic 140 with Dow A-4094 primer	0.082
Filter glasses and adhesive	
1 x 2 cm x .006" thick coated microsheet bonded with Dow Corning Sylgard 182	0.112

5.0 TEST DEVELOPMENT OF SOLAR CELL MOUNTED DEPLOYABLE SUBSTRATES

5.1 FLEXIBILITY OF SUBSTRATES WITH ATTACHED SOLAR CELLS

Test Set-up (see Fig. 13)

Fabricate one test fixture as shown.



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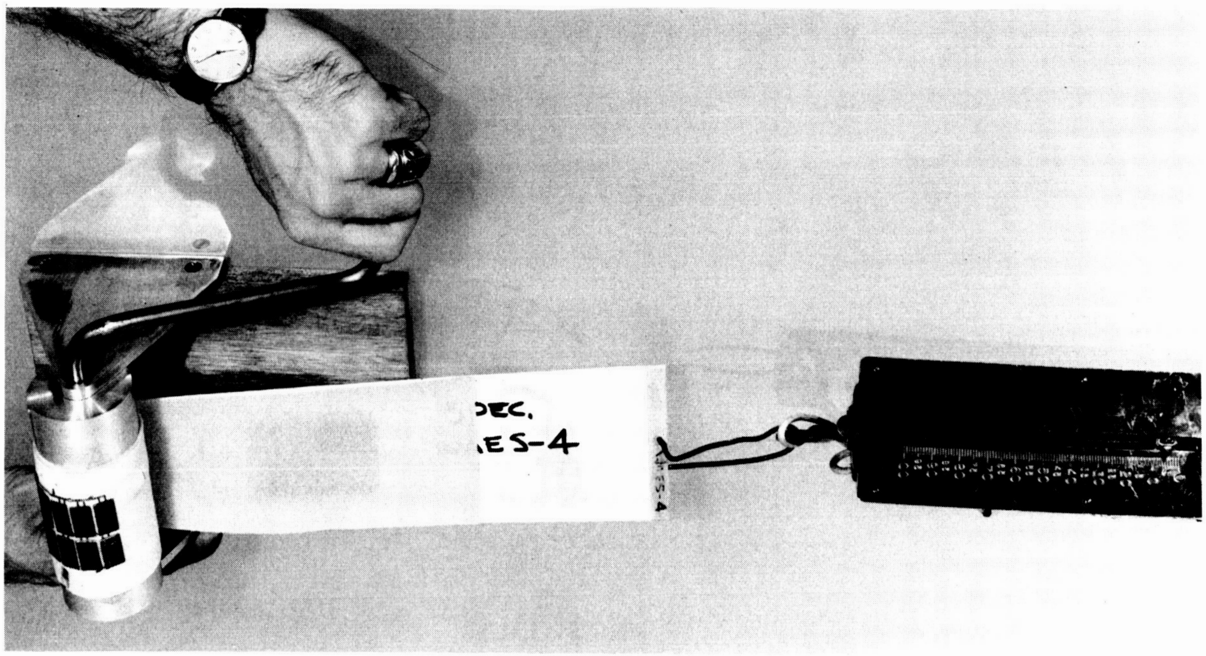


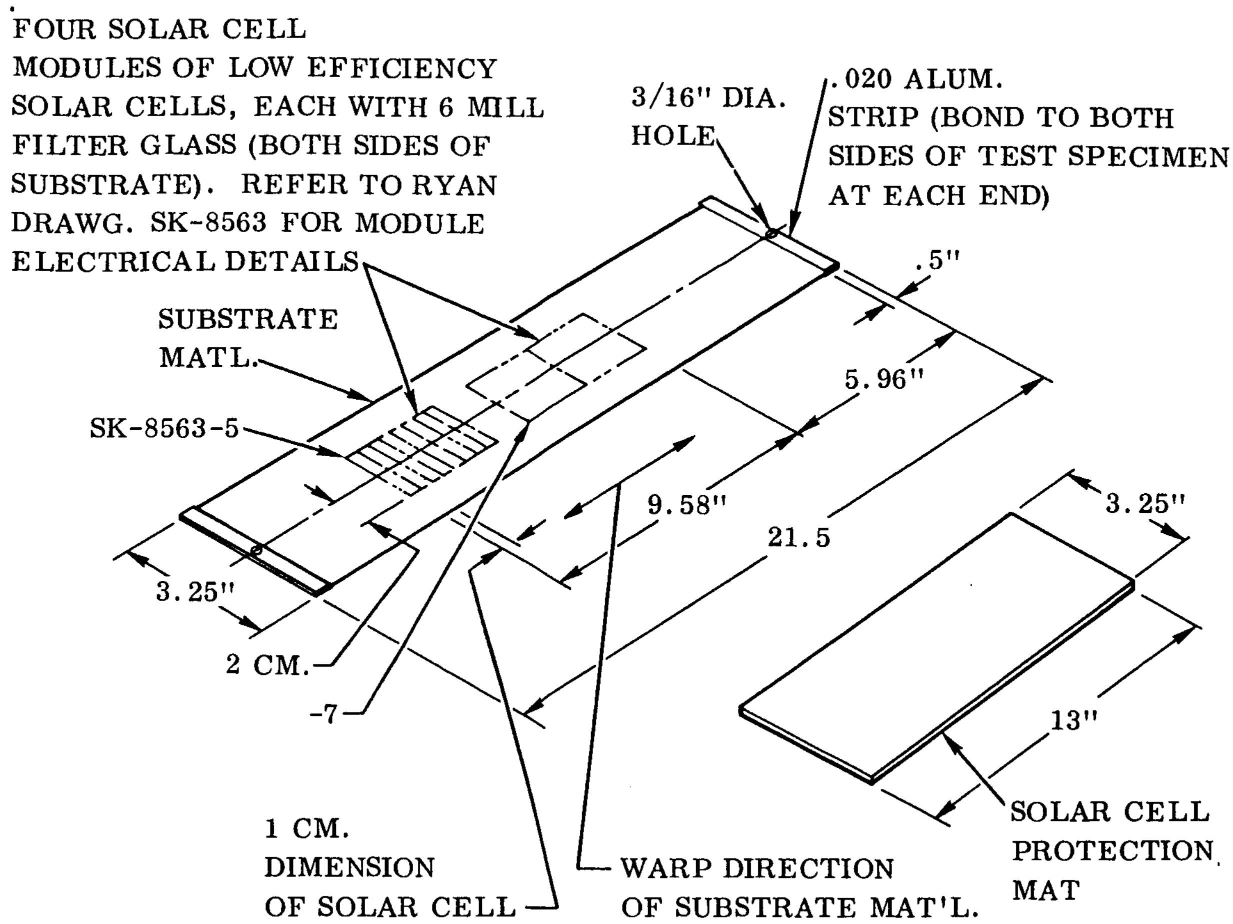
Figure 13. Wrap Test Setup

All Teflon coated glass cloth to be etched per the following process:

1. Clean in Acetone
2. 15 minutes etch in Sodium Naphthalene Complex
3. Rinse in Acetone
4. Rinse in De-ionized water
5. Dry at 150° F

Test Specimens

Fabricate per the following:



Typical test specimen

Specimen No.	Substrate Mat'l	Protection Mats	Solar Cell Adhesive		Filter Glass Adhesive
WAES-1	Armalon 405-112	Polyurethane Foam (2lbs/ft^3 density) .06" and .08" thick	**		Dow Corning Sylgard 182
WAES-2	***		****		
WAES-3	Armalon 403-108			Δ	
WAES-4	***			Δ	

Notes
1. Do not prime silicone substrate.
2. All Armalon to be etched in Ryan lab. prior to bonding.
3. All substrate material to be cleaned with iso-propyl alcohol prior to priming or bonding.

Δ Dow Silastic 140 with Dow A-4094 primer
** RTV 40 (catalyzed with thermolite 12) with PRC 1902 primer
*** 108 glass cloth coated with RM-5 white silicone rubber (3M Co.)
**** RTV 40 (catalyzed with thermolite 12) with PRC 1901 primer

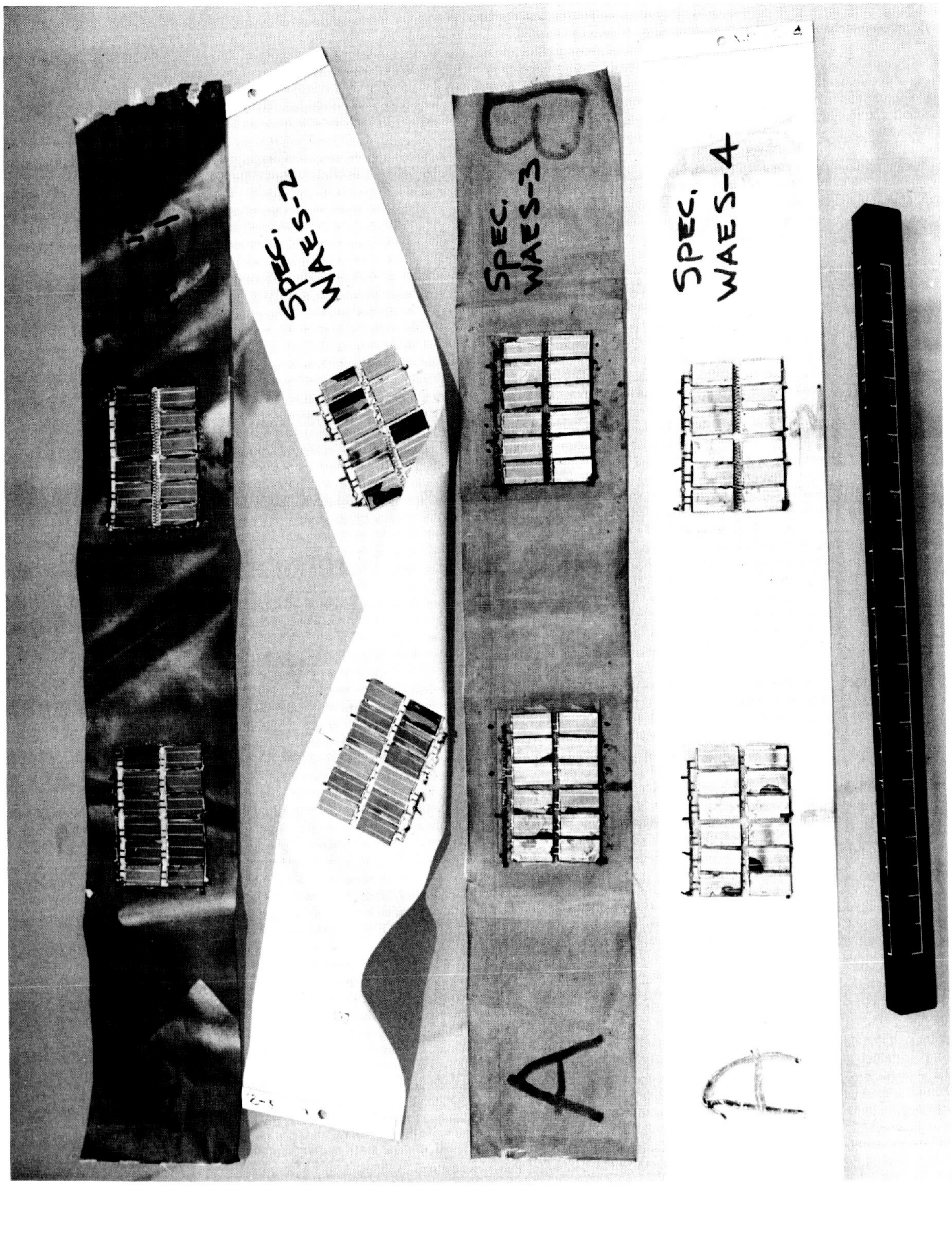


Figure 14. Wrap Test Specimens - After Test

Test Objective

The objective of this test is to determine the compatibility of wrapping solar cell substrates around a roller. The roller radius is selected to simulate the minimum bend radius of the packaged segmented beam concept. Various substrate materials and solar cell bond adhesives are investigated under wrap tensions of different magnitudes. Solar cells, wired into representative modules, allow visual and electrical investigation of packaging and deployment effects. Electrical power degradation investigations following each test allow prediction of effects after a greater number of wrap cycles.

Although tests are conducted at room temperature, conditions are considered to be simulated since the substrate material remains flexible between the temperature extremes (-94° F to +158° F) possible during deployment. Thin (<1/8") flexible polyurethane foam solar cell protection mat will become somewhat stiff at the low temperature extremes but not to any degree (as experienced by a dry-ice test) which will damage solar cells during deployment. The silicone bonding adhesives have little deviation in machanical properties between the temperature extremes.

Test Procedure

1. Electrically check power output of each specimen.

2. Wrap one specimen around roller with the .06 in. thick protection mat, then with the .08 in. thick protection mat to determine minimum mat thickness feasable. Use the selected mat for the following test applicable to each specimen.

3. Make sketch of each specimen showing physical imperfections.

   Simulation of packaging and unpackaging cycle:

4. Wrap, then unwrap specimen while controlling fabric tension with a graduated spring tension scale. The fabric tension shall be held constant at 5 lbs (1.5 lbs/in. of width) which is considered to be a reasonable packaging tension. Reverse specimen 180 degrees in its plane and repeat wrap and unwrap procedure. This constitutes one wrap cycle on each solar cell module.

5. Note any mechanical damages resulting from test. Electrically check power output of each specimen.

6. Note any mechanical damages which might have occurred during electrical check and in handling. Repeat items 4 and 5 with the exception that the number of wrap cycles shall be increased to 6.

7. Note any mechanical damages which might have occurred during electrical check and in handling. Repeat items 4 and 5 with the exception that the number of wrap cycles shall be increased to 20.

Simulation of centrifugal force deployment and re-folding cycle:

8. Note any mechanical damages which might have occurred during electrical check and in handling. Conduct one wrap cycle with fabric tension at 10 lbs. Repeat item 5 with the exception that the electrical check shall consist of checking continuity only.

9. Repeat item 8 with fabric tension increased to 15 lbs. Increase fabric tension by 5 lbs. for each subsequent test until a major mechanical failure occurs.

10. Forward data to engineering dept. for reduction.

Test Results

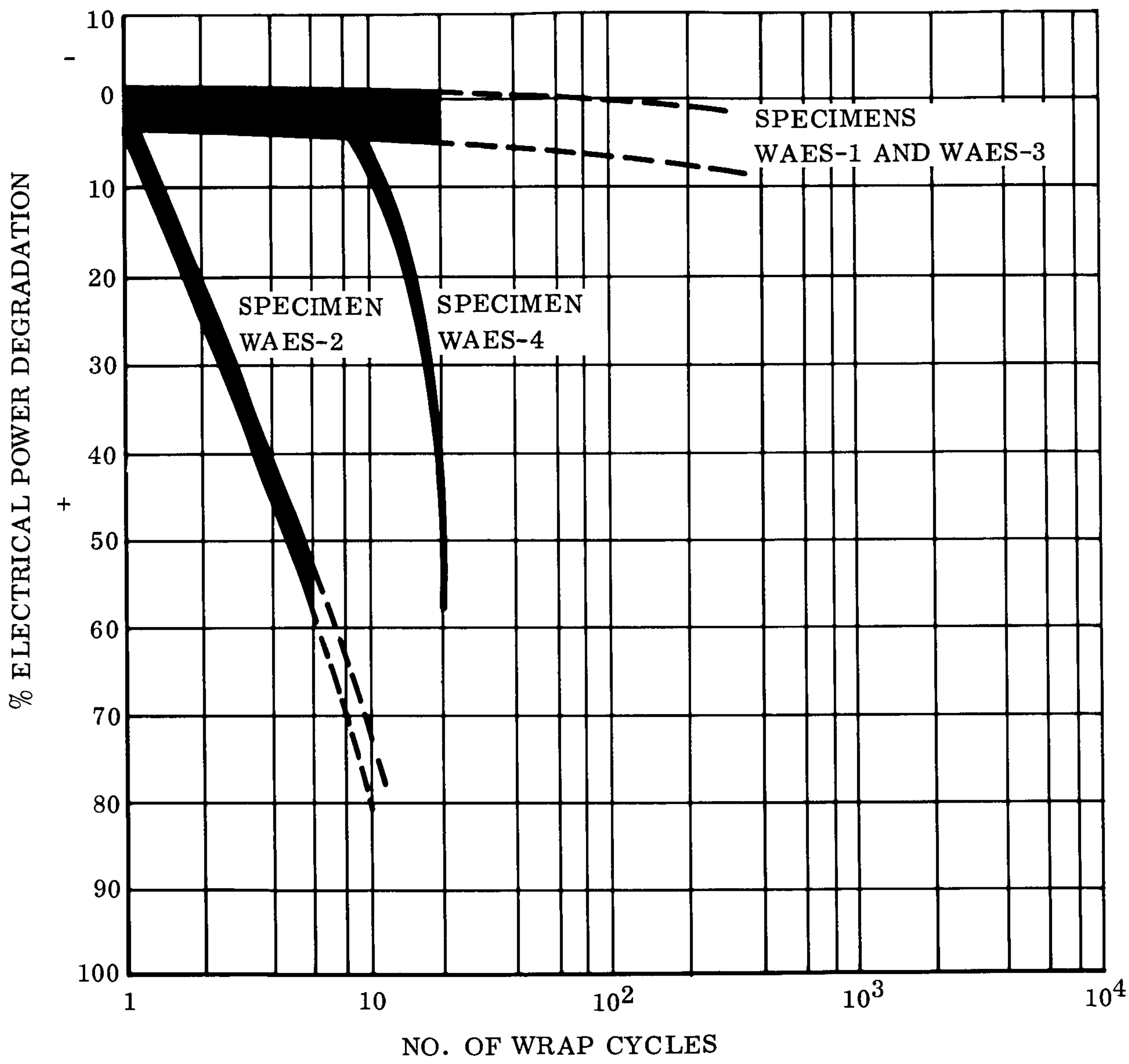
Simulation of packaging and unpackaging cycle:

The following tests were conducted with substrate wrap tension at 5 lbs (1. 5 lbs/in. of width).

No. of Wrap Cycles	Spec. No.	Module Drawg No.	Description of Mechanical Damage
1	WAES-1	SK-8563-5	None
		SK-8563-7	
	WAES-2	SK-8563-5	
		SK-8563-7	
	WAES-3	SK-8563-5	
		SK-8563-7	
	WAES-4	SK-8563-5	
		SK-8563-7	None

No. of Wrap Cycles	Spec. No.	Module Drawg No.	Description of Mechanical Damage
6	WAES-1	SK-8563-5	None
		SK-8563-7	None
	WAES-2	SK-8563-5	Module parallel
		SK-8563-7	Interconnectors broke
	WAES-3	SK-8563-5	None
		SK-8563-7	
	WAES-4	SK-8563-5	
		SK-8563-6	
20	WAES-1	SK-8563-5	
		SK-8563-7	
	WAES-3	SK-8563-5	
		SK-8563-7	None
	WAES-4	SK-8563-5	Module parallel
		SK-8563-7	interconnectors broke

THE FOLLOWING CURVES ARE BASED ON THE RESULTS OF AN ELECTRICAL CHECK OF EACH SOLAR CELL MODULE UNDER A TUNGSTEN LIGHT TOWER AT 100 MW/CM^2 WITH THE SPECIMEN AIR COOLED. THE DASH LINES INDICATE A FAIRED-IN EXTENSION OF THE TEST DATA.



Simulation of centrifugal force deployment and re-folding cycle:

Substrate Wrap Tension lbs.	Spec. No.	Module Drawg No.	Description of Mechanical or Electrical Damage	
10	WAES-1	SK-8563-5	None	
		SK-8563-7		
	WAES-3	SK-8563-5	High series resistance	Filter Glasses Broke
		SK-8563-7		
15	WAES-1	SK-8563-5	High series resistance	
		SK-8563-7		
	WAES-3	SK-8563-5		
		SK-8563-7		
20	WAES-1	SK-8563-5	Module parallel interconnector broke	
		SK-8563-7	High series resistance	
	WAES-3	SK-8563-5	Module parallel interconnectors broke	
		SK-8563-7		
25	WAES-1	SK-8563-5		
		SK-8563-7		
	WAES-3	SK-8563-5	Module parallel interconnectors broke	Filter Glasses Broke
		SK-8563-7		

No electrical discontinuity or power degradation of individual modules resulted from above tests.

Substrate Wrap Tension lbs.	Spec. No.	Module Drawg No.	Description of Mechanical or Electrical Damage	
28	WAES-1	SK-8563-5	1. Some solar cells broken 2. Discontinuity in series	Filter Glasses Broke
		SK-8563-7		
	WAES-3	SK-8563-5	1. Some solar cells broken 2. Discontinuity in series 3. Discontinuity, cell-to-cell in parallel	Filter Glasses Broke
		SK-8563-7		

Specimen WAES-3 was then subjected to 25 lbs. and 28 lbs. wrap tension respectively using .25 in. and .5 in. thick polyurethane foam protection mat (2 lbs/ft^3 density). No filter glass or solar cell breakage resulted.

Conclusions

Breakage of module parallel interconnectors indicates need for improvement in that area, such as elimination of lightening holes and an additional expansion joint. Breakage on silicone coated glass fabric indicates that substrate material to be too elastic resulting in an overload of the interconnectors. Breakage with Armalon mounted modules occurred at 20 lbs. minimum which is in excess of the required 18.7 lbs (5.75 lbs/in. of width) design load (see Fig. 9, Para. 3.4.3.3) for the segmented beam concept.

The increase in series resistance may be eliminated by using titanium silver sintered solar cells. This increase in series resistance, which occurred in all Armalon mounted modules at below the 18.7 lbs. design load is found to be a result in separation of the nickel plating from the silicone base material with the type solar cells used.

Tests show that maximum centrifugal force deployment loads cannot be safely carried in the silicone solar cells and .006 in. thick filter glasses using .08 in. thick polyurethane foam protection mat. This means that for a roll-out concept, the protective blanket thickness would possibly be too great to allow packaging in the design envelope.

The segmented beam concept is only slightly affected in that protective blanket thickness must be increased to .25 in. at the first and second folds only where load magnitudes are at a maximum.

No affects on module adhesive bonds or filter glass bands were noted.

No superiorty in the one type solar cell module wiring (mesh, drawing No. SK-8563-7) over the other (copper photo etch, drawing No. SK-8563-5) was indicated by tests. Weights of actual samples show the copper photo etch design to be 1.7% lighter than the mesh design (see Section 4.5).

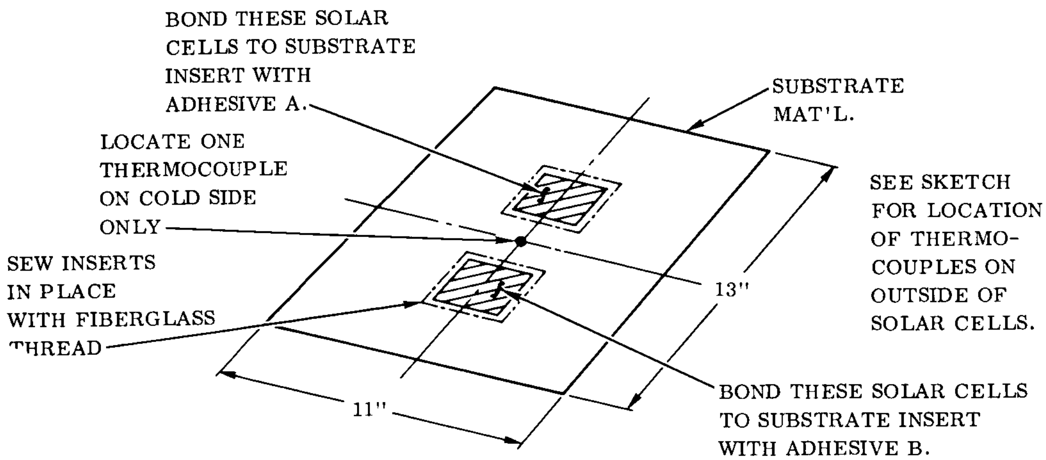
5.2 THERMAL CONDUCTIVITY THROUGH SOLAR CELLS MOUNTED TO FLEXIBLE SUBSTRATES

Test Set-Up

The mounting frame and test set-up used for Mariner "C" solar substrate specimens shall be utilized. The specimen is mounted along the four edges during test. While under vacuum, heat is applied to one side of the specimen and radiated from the opposite side to a cold wall (see Figs. 15 and 16).

Test Specimens

Fabricate per the following sketch. Refer to sketch of typical solar cell layout both sides of substrate insert.



TYPICAL TEST SPECIMEN (HEATED SIDE SHOWN)

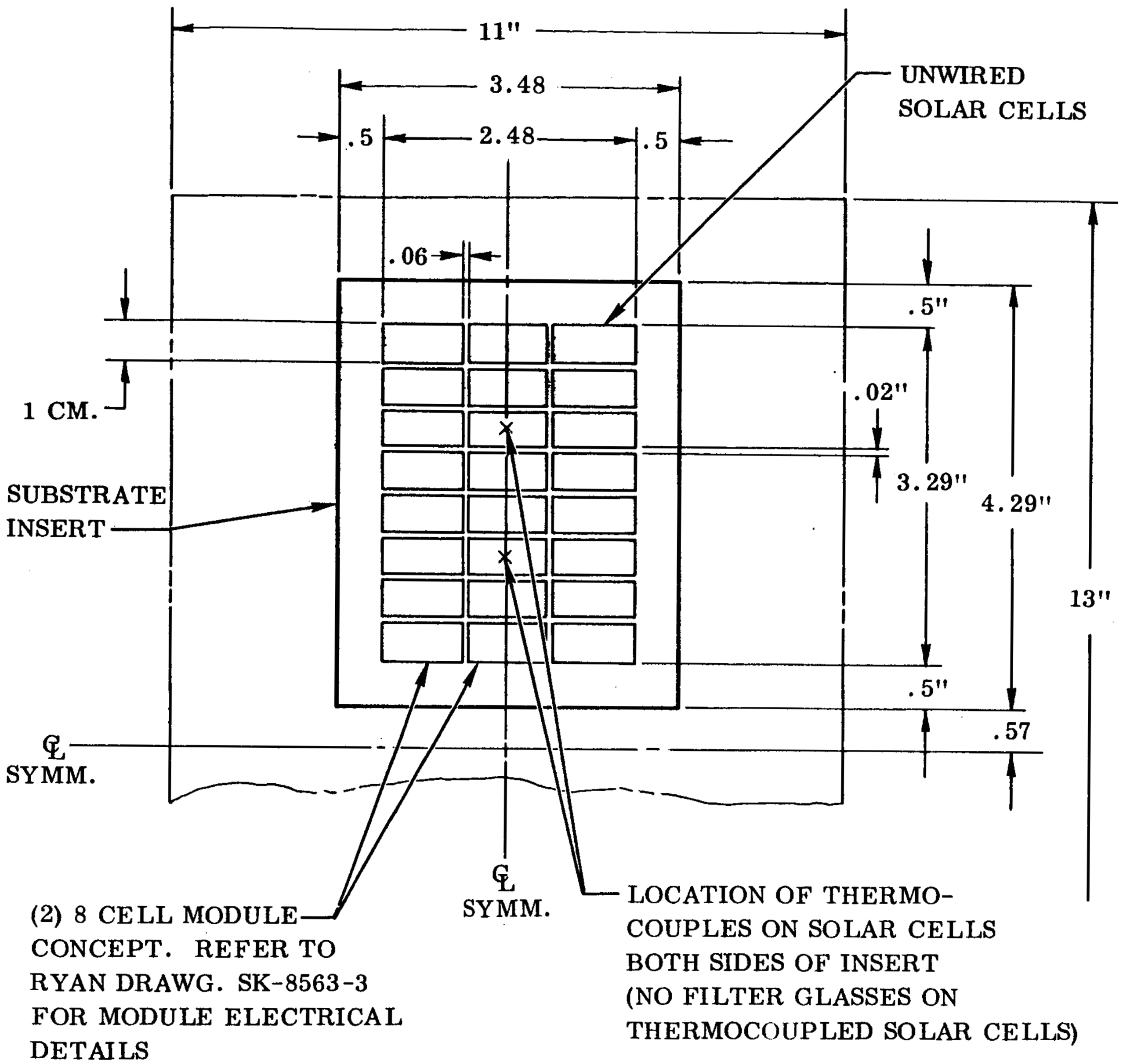
Specimen No.	Substrate Material	Solar Cell Adhesive A	Solar Cell Adhesive B	Filter Glass Adhesive	Notes
TAES-1	128 glass cloth impregnated with RP7A-828 epoxy resin	**	Δ	Dow Corning Sylgard 182	Notes: Same as for test specimens Section 5.1
TAES-2	Armalon 403-108	****			
TAES-3	***	**			

Δ Dow silastic 140 with Dow A-4094 primer

** RTV 40 (catalyzed with Thermolite 12) with PRC 1901 primer

*** 108 glass cloth coated with RM-5 white silicone rubber (3M Co.)

**** RTV 40 (catalyzed with Thermolite 12) with PRC 1902 primer



NOTE: THE .02 IN. SOLAR CELL SPACING IS INCREASED TO .05 IN. FOR THE WRAP SPECIMENS (REF. SEC. 5.1) AFTER PRELIMINARY WRAP INVESTIGATIONS PROVED THE .02 IN. SPACING TO BE TOO SMALL.

SKETCH OF TYPICAL SOLAR CELL LAYOUT BOTH SIDES OF SUBSTRATE INSERT

Test Objective

The objective of this test is to determine vacuum operating temperature vs. heat wattage input curves of solar cells mounted on both sides of a flexible substrate. Various substrate material and solar cell adhesive combinations will be investigated. Temperatures to -94° F on the cold side radiating to space and to +158° F on the hot side looking at the sun will be considered. Comparison will be made with theoretical wattage temperature curves. Solar cells, wired into representative modules, allow visual and electrical investigation of test environment effects.

Test Procedure

1. Attach thermocouples (28 Ga. copper constantan) directly to solar cells with a minimum of Epon 828 epoxy adhesive (epicure 874 catalyst). Clean solar cells with acetone prior to bonding.

2. Clean specimen insert and record voltage vs. amperage curves.

3. Hand sew insert to fabric frame using fiberglass thread.

4. Mount specimen in test fixture so silicone rubber heater blanket does not touch thermocouple. Heater blanket surface is approximately .25" from fabric surface.

5. Reduce test chamber pressure to < 10^{-4} torr.

6. Record specimen temperature at thermocouple locations after temperature stabilization and cold wall flooded with liquid nitrogen. Recordings will be made for heat wattage inputs to the heater blanket of 0, 15, 30, 50, and 65 watts/ft^2. The above wattage inputs are based on a desired wattage vs. temperature curve plotted between -94° F and +158° F.

7. Remove specimen from chamber and visually check.

8. Electrically check and compare voltage vs. amperage curves of each solar cell module with that prior to test.

   Note: Handle specimen inserts with clean white gloves at all times. Specimen inserts to be protected with a clean plastic bag when not in use.

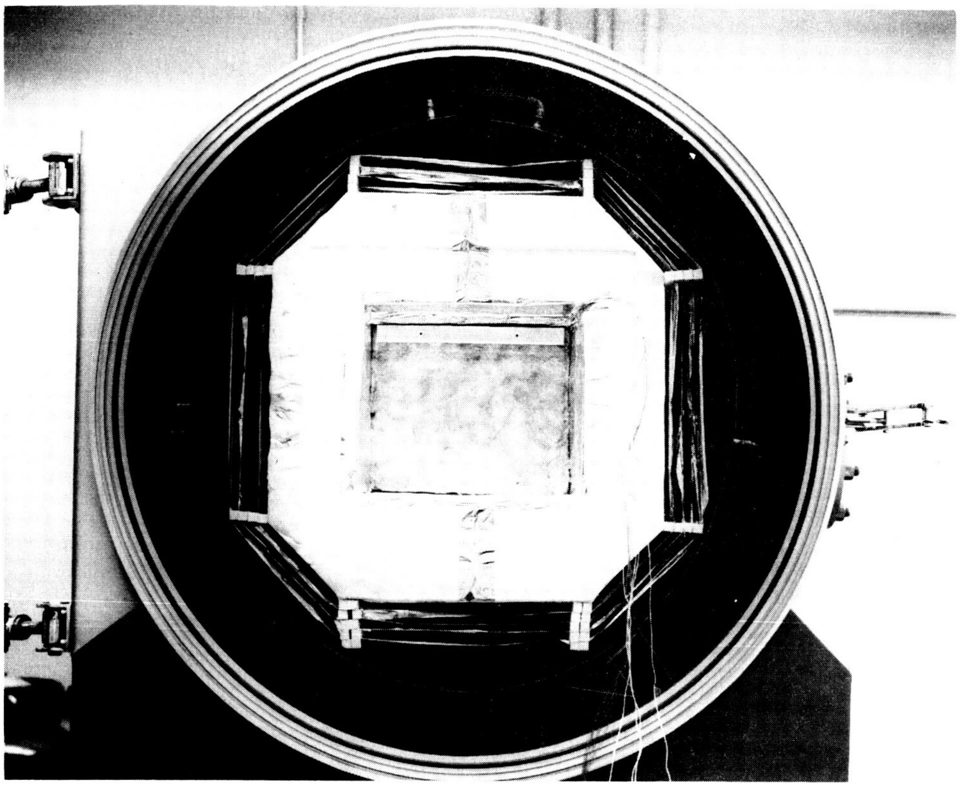


Figure 15. Mounting Frame in Vacuum Chamber

Figure 16. Thermal Test Specimen in Mounting Frame

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Pre-Test Observations of Thermocouple Bond Adhesion

Initially, the intent was to run tests with thermocouples bonded to filter glasses to give temperature gradients between extreme points 28 Ga. Copper Constantan thermocouples were bonded to the acetone cleaned filter glasses with Eastman 910 adhesive. Bond failure at the filter glasses resulted with the first specimen tested.

The thermocouples were re-bonded to the filter glasses using Epon 828 epoxy resin and epicure 874 catalyst. Cracks developed in the filter glasses during test.

Filter glasses were then removed from all solar cells to be thermocoupled, filter glass adhesive removed, solar cells cleaned with acetone, and thermocouples re-bonded using Epon 828 epoxy resin. Actual testing was then begun.

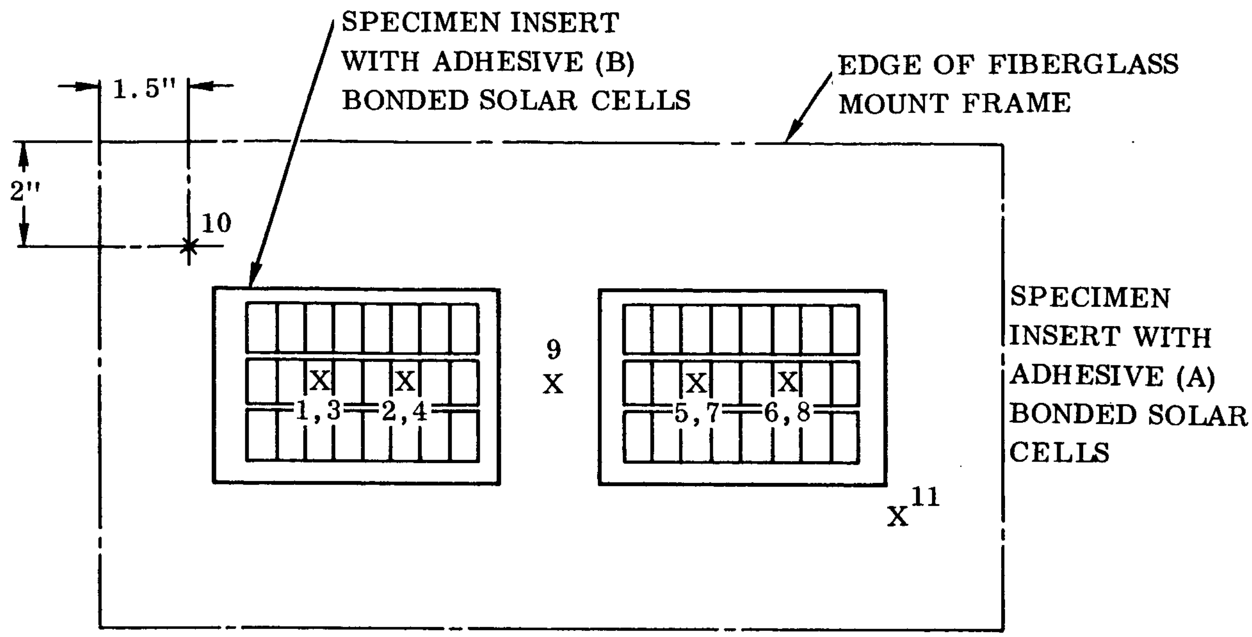
Test Results

All thermocouples remained intact on the first specimen tested (TAES-2). After test, light movement of each thermocouple to check intactness caused breakage of a portion of solar cell, with thermocouple still intact, from the solar cell surface. The second specimen (TAES-3) tested resulted in failure of the thermocouple bond at the solar cell with 3 out of 8 thermocouples. The third specimen tested (TAES-1) had thermocouples bonded to sandpaper roughened solar cells using a 1 to 1 mixture of Jones-Dabney epoxies 5132 and 504 catalyzed with epicure 874 (epoxy to catalyst ratio is 10 to 4). No thermocouple bond failures occurred during test of the third specimen.

Examination of the specimens following test found no visual mechanical effects of the solar cells, adhesive bonds or any electrical degradation.

Thermal Considerations

One of the objectives of the vacuum test is to determine the thermal properties of different solar cell assemblies. In order to establish the trends and temperature range in which to conduct the test it was desirable to conduct a thermodynamic analysis. An estimate was made based on the assumptions that the net heat radiated from the heater to the cell assembly was equal to the net heat radiated from the assembly to the cold wall, once equilibrium was reached. The net heat flux through the test chamber walls and the temperature drop across the assembly was considered negligible.



VIEW LOOKING TOWARD
SPECIMEN FROM COLD WALL

Thermocouple No.	Location
10, 11	Heater Blanket Toward Specimen
1, 2, 5, 6	Solar Cell Toward Cold Wall
3, 4, 7, 8	Solar Cell Toward Heater Blanket
9	Substrate Toward Cold Wall
16	Cold Wall

Cross-Reference of Thermocouple Locations

If the heat flux/area is considered constant for the heater then

$$\left(\frac{Q}{A}\right)_{\substack{\text{Heater}\\ \text{to}\\ \text{Assembly}}} = \left(\frac{Q}{A}\right)_{\substack{\text{Assembly}\\ \text{to}\\ \text{Cold Wall}}}$$

for equilibrium.

Heat radiated from cell assembly is

$$\left(\frac{Q}{A}\right)_{a-w} = \bar{\sigma} F_e F_a \left(T_a^4 - T_w^4\right)$$

where the following constants are assumbed

$\bar{\sigma} = 0.173 \times 10^{-8}$

$F_e = \Sigma_1 \Sigma_2 = 0.83$

$F_A = 0.78 =$

a = Cell assembly

w = Cold wall

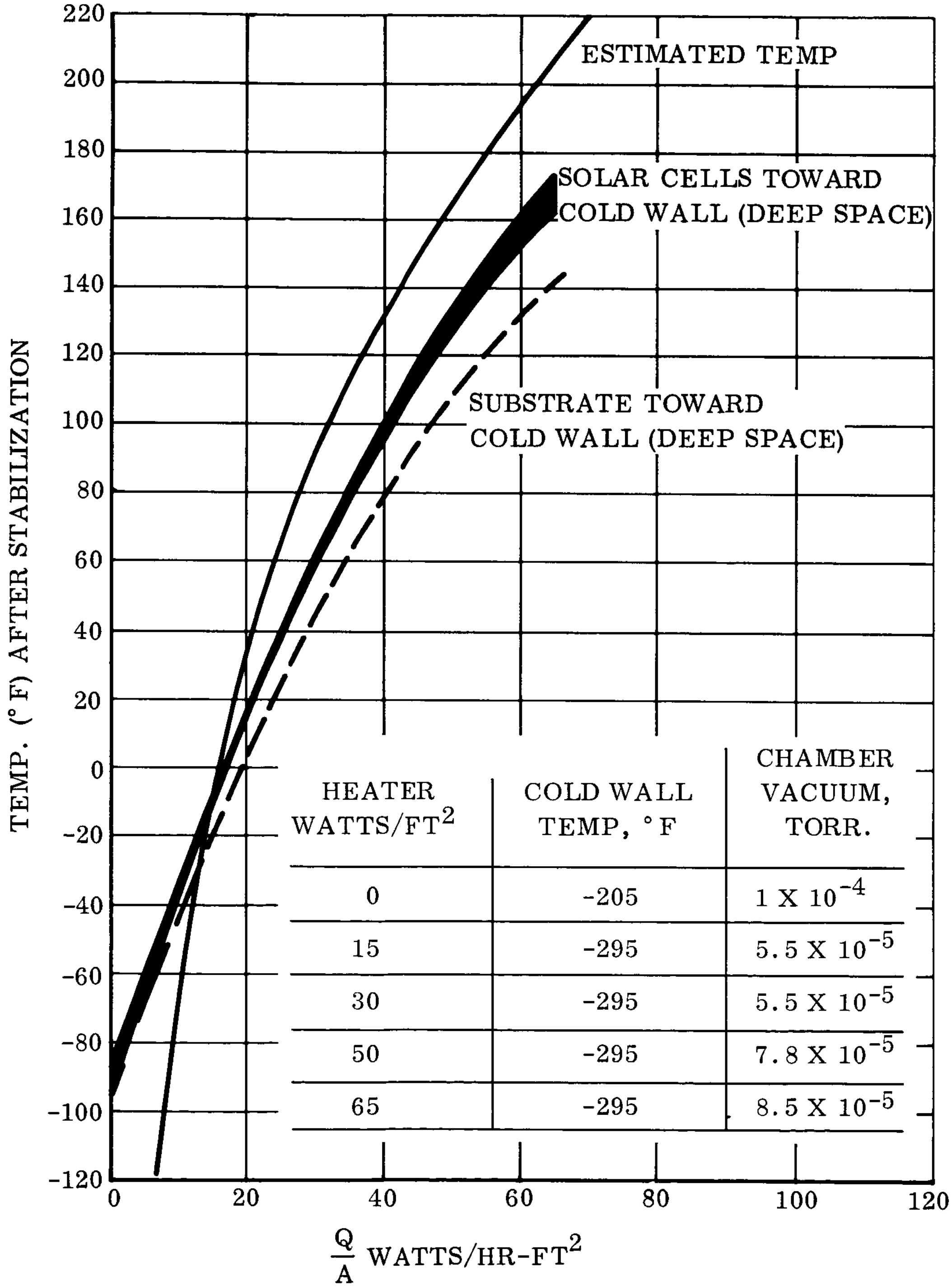
The heat flux as a function of assembly temperature, assuming a constant cold wall temperature of -280° F, is

$$\left(\frac{Q}{A}\right)_{\text{heater}} = 0.1125 \left[\left(\frac{T_a}{100}\right)^4 - \left(\frac{179}{100}\right)^4\right] .$$

Conclusions

No superiority of any one type substrate or solar cell adhesive was noted after testing. Temperatures recorded at solar cells indicate negligible effects due to substrate and adhesive materials.

TEST DATA FOR
SPECIMEN TAES-2



HEATER WATTS/FT^2	COLD WALL TEMP, ° F	CHAMBER VACUUM, TORR.
0	-205	1×10^{-4}
15	-295	5.5×10^{-5}
30	-295	5.5×10^{-5}
50	-295	7.8×10^{-5}
65	-295	8.5×10^{-5}

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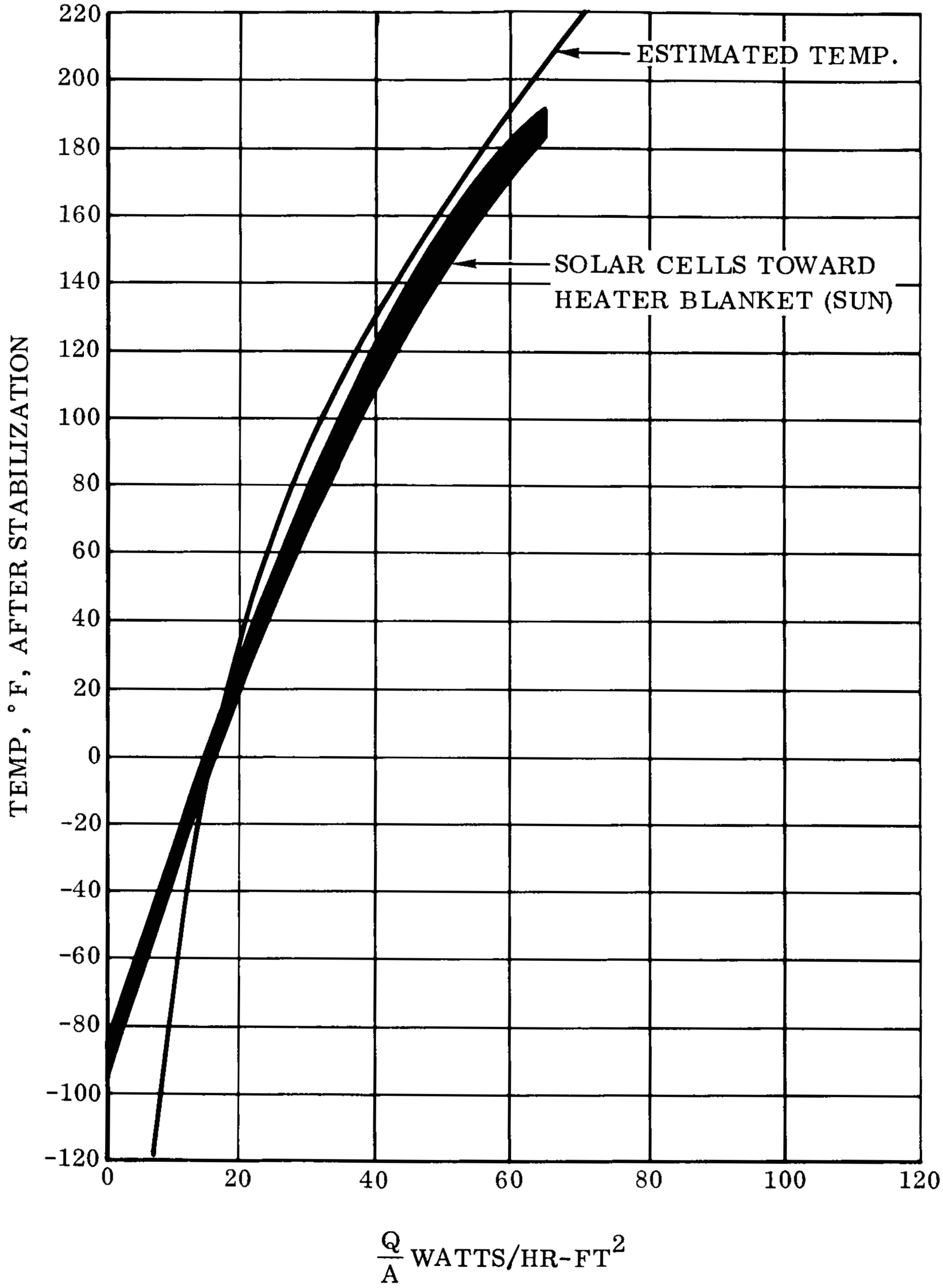
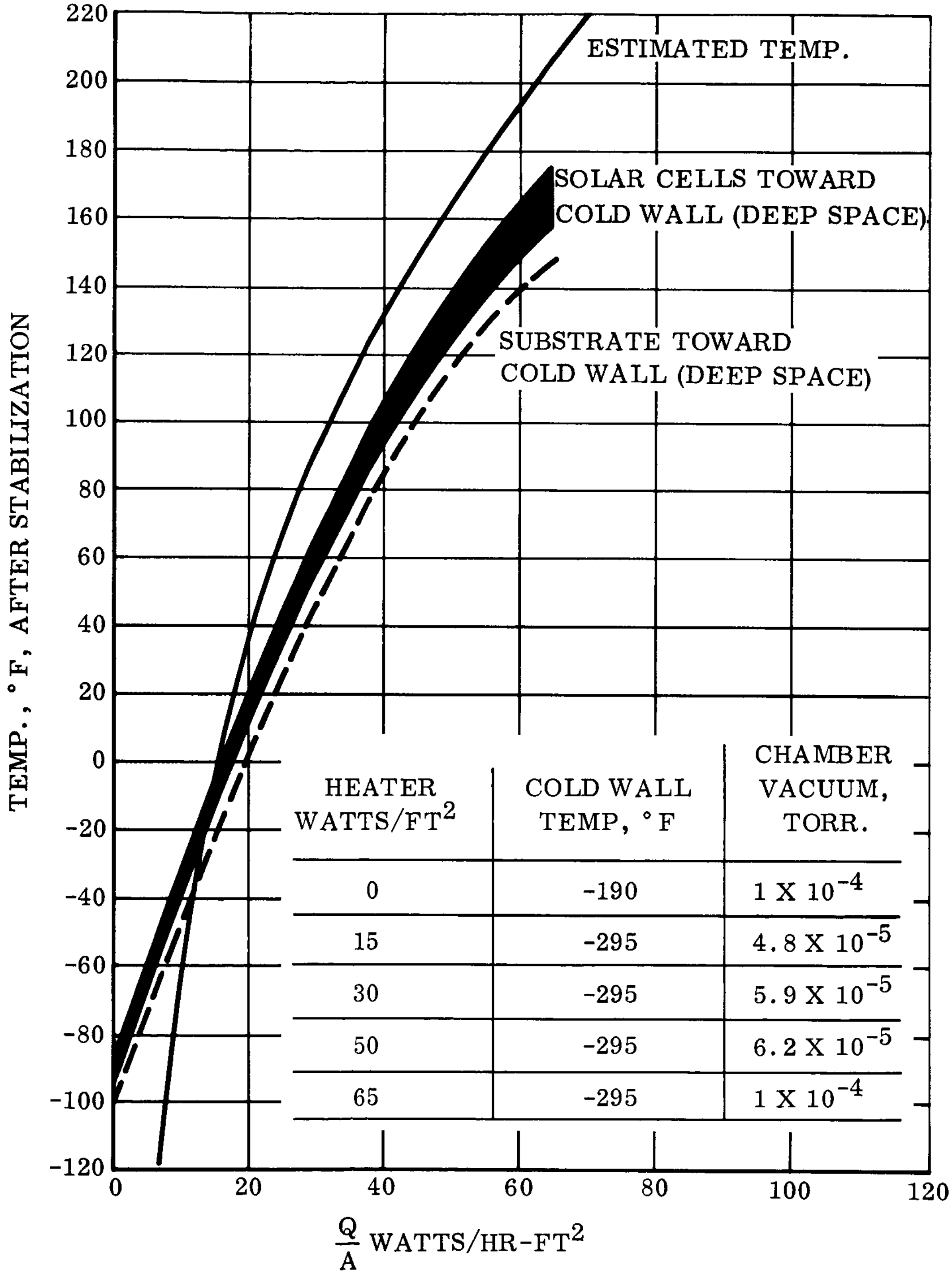
TEST DATA (CONTINUED)
FOR SPECIMEN TAES-2



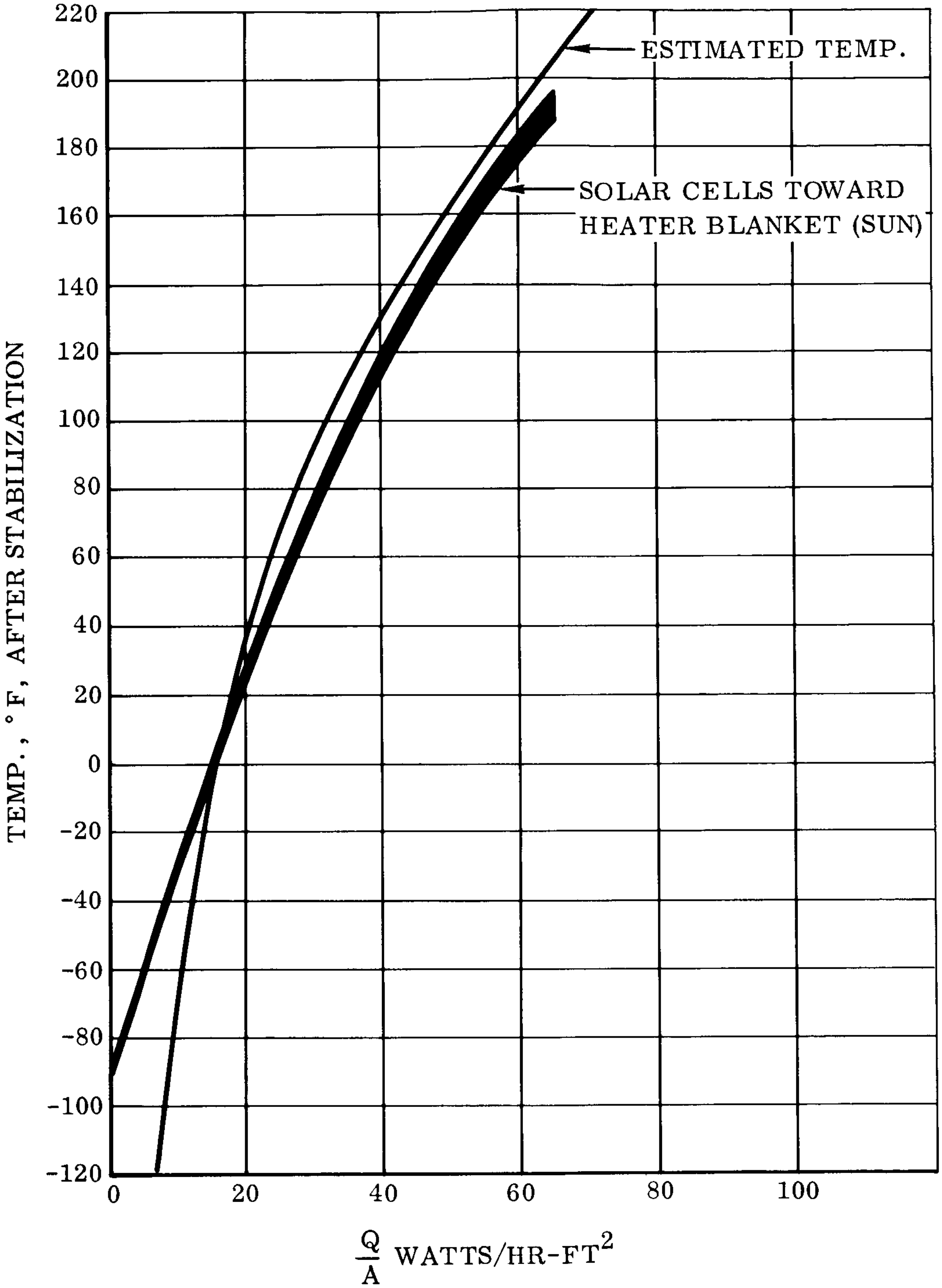
TEST DATA FOR
SPECIMEN TAES-3



HEATER WATTS/FT^2	COLD WALL TEMP, °F	CHAMBER VACUUM, TORR.
0	-190	1 X 10^{-4}
15	-295	4.8 X 10^{-5}
30	-295	5.9 X 10^{-5}
50	-295	6.2 X 10^{-5}
65	-295	1 X 10^{-4}

RYAN 64B119

TEST DATA (CONTINUED)
FOR SPECIMEN TAES-3



5.3 THERMAL CYCLING OF SOLAR CELLS MOUNTED TO FLEXIBLE SUBSTRATES

Test Set-Up

Use test set-up, reference Section 5.2.

Test Specimens

Use test specimens, reference Section 5.2.

Test Objective

The objective of this test is to determine effects of thermal cycling in vacuum on solar cells mounted to both sides of flexible substrates. Various substrate material and solar cell adhesive combinations will be investigated.

Solar cells, wired into representative modules, allow both visual and electrical investigation of test environment effects on electrical connections. Investigations of electrical power degradation at the end of two test cycles will allow prediction studies of same after greater time lengths in space environment.

Test Procedure

1. Mount specimen in test fixture so heater blanket does not touch thermocouple. Heater blanket surface is approximately .25" from fabric surface.

2. Reduce chamber pressure to $< 10^{-4}$ torr.

3. Record specimen temperature (quarter hour intervals) at thermocouple locations with liquid nitrogen flooded cold wall. Heat wattage inputs to the heater blanket will be determined from the thermal conductivity test to give a maximum temperature of approximately +158° F. A minimum of two cycles from approximately +158° F to -94° F and return shall be applied at a rate of approximately one cycle in a 2 hour period.

4. Remove specimen from chamber and visually check.

5. Electrically check and compare voltage vs. amperage curves of each solar cell module with that after thermal conductivity test.

6. Repeat items 1 through 5.

<u>Note</u>: Handle specimen inserts with clean white gloves at all times. Specimen inserts to be protected with a clean plastic bag when not in use.

Test Results

It is intended that these tests be conducted in Phase II of the overall solar array development program, time not allowing in Phase I.

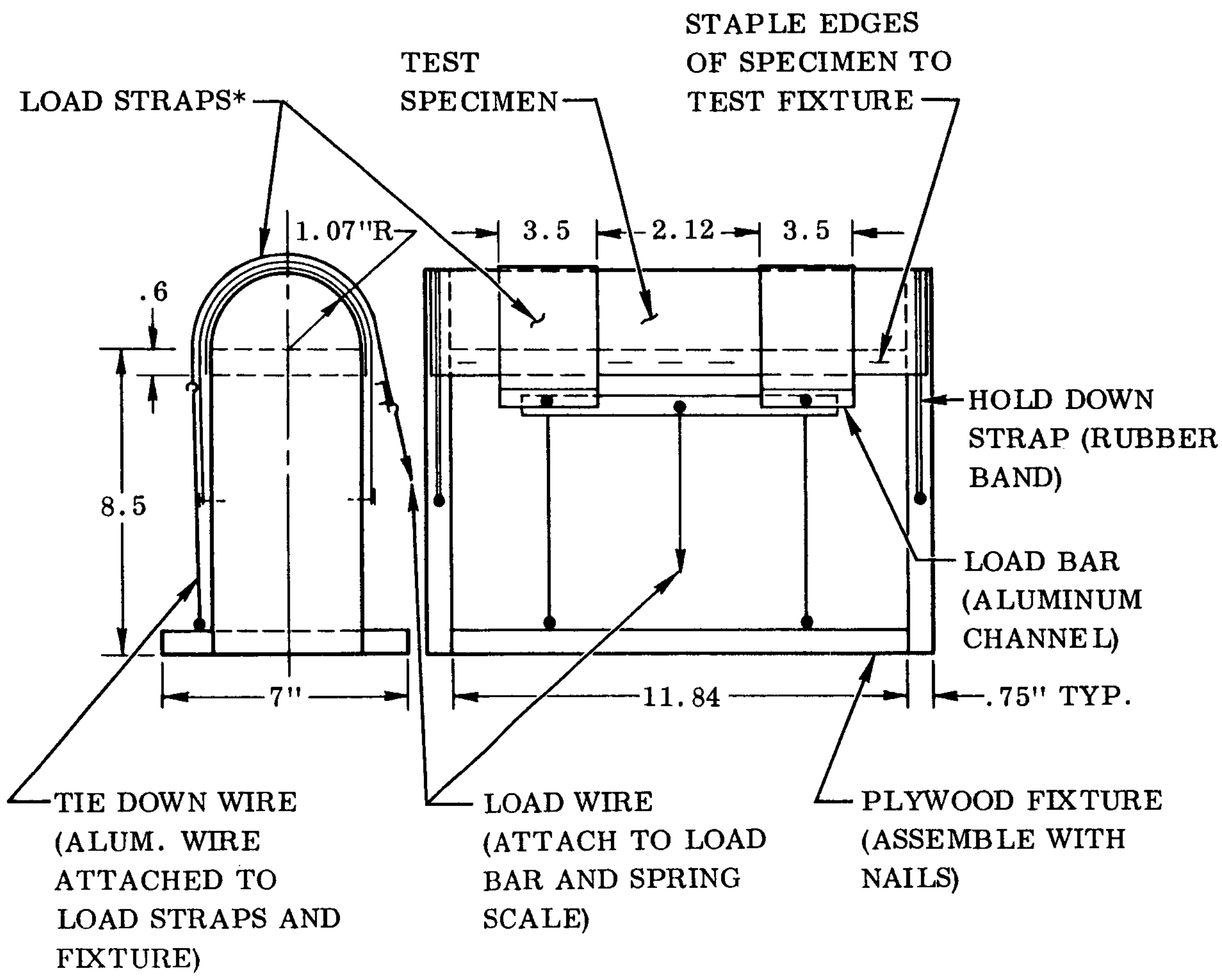
5.4 RIGIDITY OF CURVED FLEXIBLE SUBSTRATES WITH ATTACHED DUMMY SOLAR CELLS

Test Set-Up

Fabricate one test fixture as shown.

TEST SET-UP

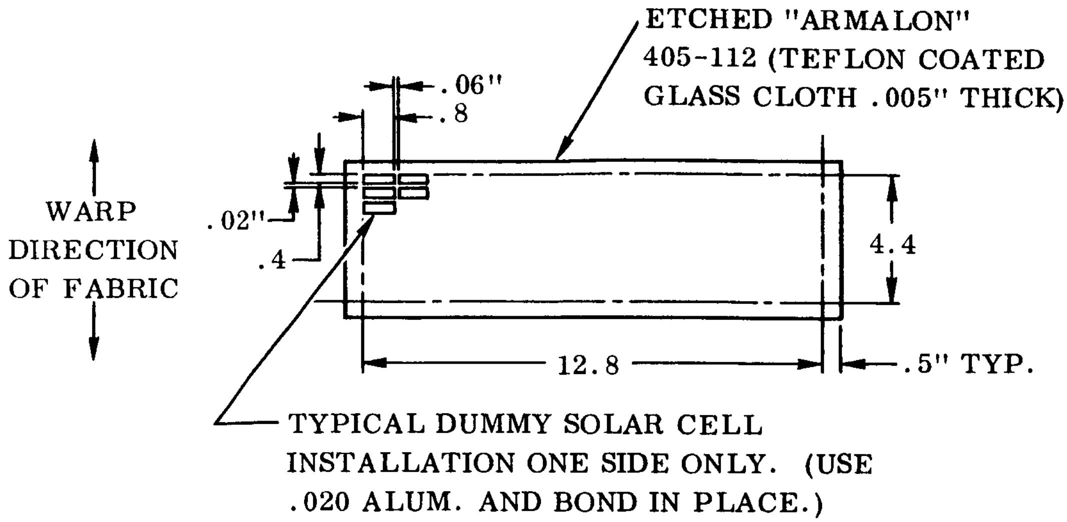
FABRICATE ONE TEST FIXTURE AS SHOWN:



*108 GLASS CLOTH COATED WITH RM-5 WHITE SILICONE RUBBER (3M COMPANY)

Test Specimen

Fabricate per the following:



Test Objective

Test A -

The objective of this test is to determine the capability of a curved section of flexible substrate to carry radial loads. The idea is of direct concern in the segmented beam design concept when deployment loads are restrained in the unstabilized outboard fold of the flexible substrate material then beamed to the segmented side beams. The substrate material was selected for test based on stiffness characteristics. Attached dummy solar cells of equivalent stiffness simulate solar cell stabilization.

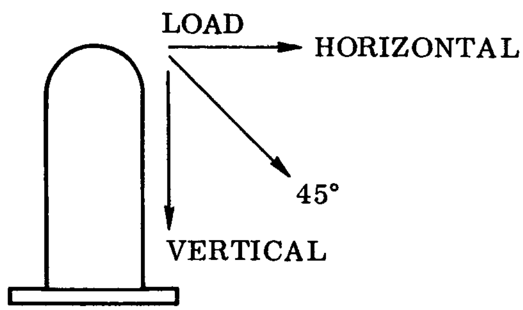
Test B -

The objective is to determine the load carrying ability of the solar cells for the above condition. A back-up medium will be used if shown necessary based on the results of Test A.

Test Procedure

Test A -

Although the test is conducted at room temperature, conditions are considered to be simulated since the substrate material remains flexible between the temperature extremes. A steady state load is applied to the load bar. The load shall be applied separately in each of the following three directions: horizontal, 45 degrees, vertical. The load at which deflections become excessive shall be noted for each direction.



SIDE VIEW OF
TEST FIXTURE

Test Results (see Fig. 17 and 18 showing unloaded and loaded conditions respectively)

Test A

	Test Load, lbs		Req'd Load, lbs	
Load Direction	Total	Per inch of Ribbon	Total	Per inch of Ribbon
Horizontal	4	0.57	15	2.14
45 Degrees	4	0.57	15	2.14
Vertical	4	0.57	15	2.14

Conclusions

Test A -

Test results show the need for substrate back-up material, such as a rigid polyurethane foam block, to provide the load carrying capability required. The rigid foam, faced with flexible foam to reduce solar cell load concentrations, would be expelled into space upon deployment to prevent condensation on solar cell surfaces.

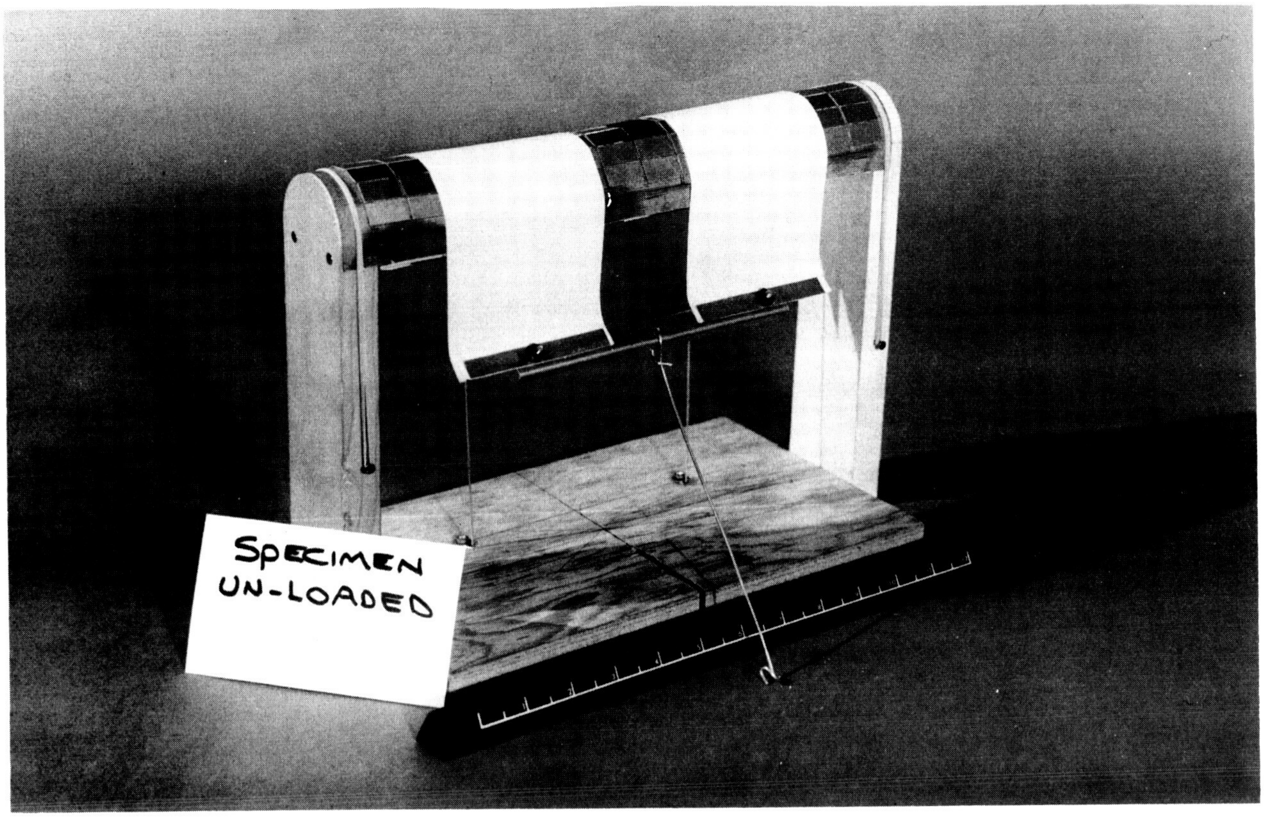


Figure 17. Substrate Rigidity Test Setup

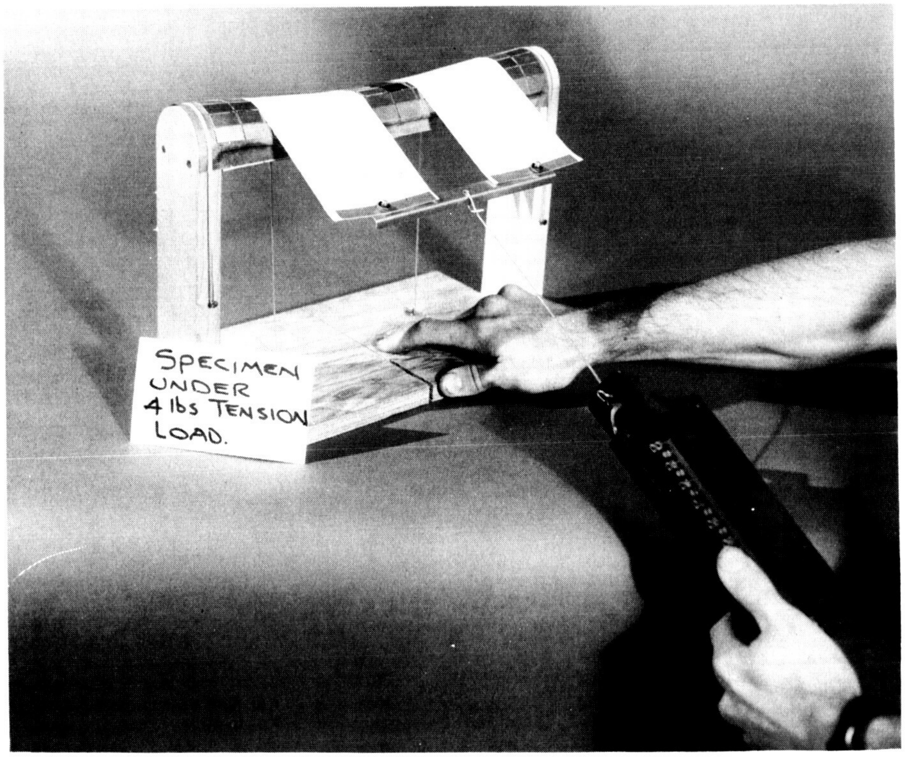


Figure 18. Substrate Rigidity Test

Test B -

A rigid polyurethane foam (2 lbs/ft^3 density), cut to the required curvature, was used as the substrate back-up material. Over this was placed the substrate with dummy solar cells, a .25 in. thick flexible polyurethane foam (2 lbs/ft^3 density) protection mat as required (see test results, Section 5.1), and wrap test specimens WAES-2 and WAES-4. The simulated deployment restraint load was induced in the solar cells with silicone coated glass fabric load straps. No solar cell or filter glass breakage was found at the test load shown below.

Test Load, lbs		Req'd Load, lbs	
Total	Per inch of Ribbon	Total	Per inch of Ribbon
69	10.62	69	10.62

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The Phase I effort was to be directed toward concept evaluation and detail investigations, culminating in the definition of a design to be further developed for full-scale applications. Seventeen different concepts were investigated for their ability to fulfill the various design parameters. Layouts of these concepts were completed in various stages of detail to investigate various aspects of particular concepts. Where layout investigation was inadequate, models were constructed to illustrate a point. A simple model of a full-scale substrate was fabricated and weighted to simulate completed hardware. A full length 8 foot strip of simulated solar cells was fabricated and rolled to investigate the effects of loading, the effect of cushioning material, and to investigate packaging envelopes. A 1/2-size working model was constructed of the selected concept to demonstrate operation. Materials and adhesives were investigaged and solar cell modules were fabricated and tested as described in Sections 4.0 and 5.0.

The result of the above work was the production of preliminary engineering drawings which could be used as the basis for fabrication of a proof-of-principle unit. Effort in detail design was carried beyond the stage originally proposed, because of the desire to work out all the structural, deployment and rigidizing problems to a reasonable solution which would insure design confidence. In doing this, Ryan was also able to present a very detailed and accurate weight breakdown which was well within the weight envelope (Ref. Para. 3.4.3.1).

Due to delays and setbacks in the test program, the thermal cycling tests were not run and this testing must be projected to Phase II. Although the testing is essential, any effect the results may have on the present design could certainly be incorporated before hardware fabrication.

Investigation was started but not completed on other methods of using the volume inside the shroud for packaging this and larger arrays. Recommendations on findings are presented in the following section.

In summary, Ryan has, by fulfillment of its proposed task, presented a good and reasonable solution to the parameters set forth by Goddard.

6.2 RECOMMENDATIONS

From past experience and layout, investigation, model construction, technical analysis and testing accomplished in Phase I effort, certain facts were discovered, or theories were proved or disproved. The following is a collection of various findings which are presented here as recommendations:

1. The series-parallel method of solar cell module construction (Ref. Fig. 8) should certainly be employed, since the flexible nature of the array presents greater possibility for cell damage than a rigid substrate. Any damage would be minimized in its effect to overall array electrical output.

2. The difference in design of the cell connectors which were created to provide for flexibility at the bend areas revealed that the methods were equivalent. Both proved quite satisfactory in providing flexibility without failure.

3. Original spacing between cells of .020" did not prove adequate to allow sufficient module bending. The adhesive, used to attach modules, flows into the spaces and tends to prevent the module from flexing. The cell gap was increased to .050" on all test modules after this discovery and good results were obtained. It is recommended, therefore, that a minimum gap of .045" be used for cell spacing in areas requiring flexibility.

4. Substrate materials chosen are adequate and compatible with bonding materials. The semi-rigid sections of epoxy impregnated glass cloth and the flexible areas of Teflon coated glass cloth both present a good cell mounting area when a Dow Silastic 140 adhesive and A-4094 primer are used for laying cells and making all other joints. The material thickness chosen was adequate to take expected loads, provide flexibility and remain within the weight envelope. No change is recommended here.

5. A recurring limitation in the concept investigation phase of this program was the problem presented by the particular package envelope of 4" x 13" x 25". Although the design presented falls within this package size, we fell that the volume inside the shroud could be used more advantageously, and would allow the application of the basic segmented beam concept, with greater freedom in the region of larger array packaging and packaging present area arrays in different shaped envelopes. An example of this

recommendation is: Assume four packaged arrays arranged as shown in Figure 9. If advantage could be taken of the volume inside a shroud surrounding the packages, a roll of cells 25" wide and 5.9" in diameter could be used. Thus, the same area array could be deployed and would be only 1/2 the length, but twice the width. The basic advantage here is that the present high loading of the substrate and cells during deployment, in terms of pound per inch of width, could be reduced to at least half, and reduce the amount of protection required to prevent cell damage. Other methods of stowing the array are shown in Figure 10.

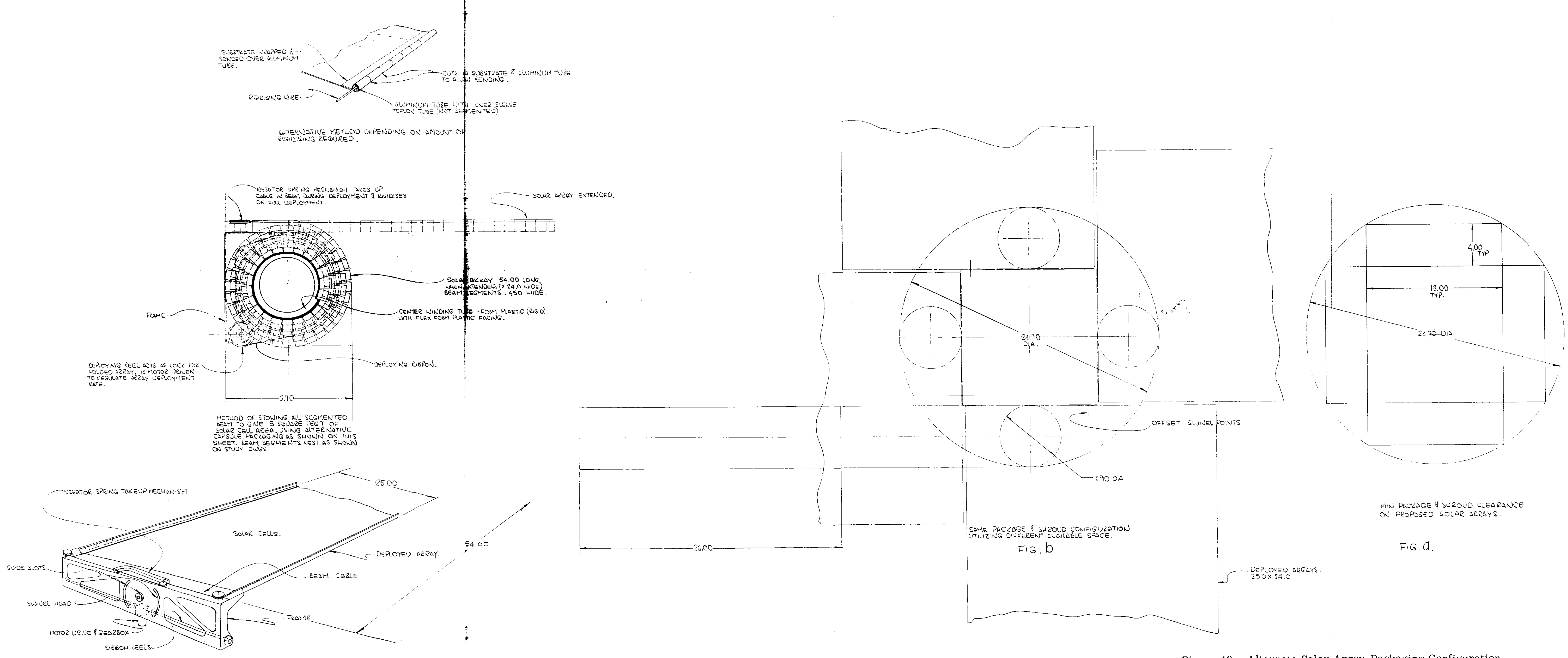


Figure 19. Alternate Solar Array Packaging Configuration

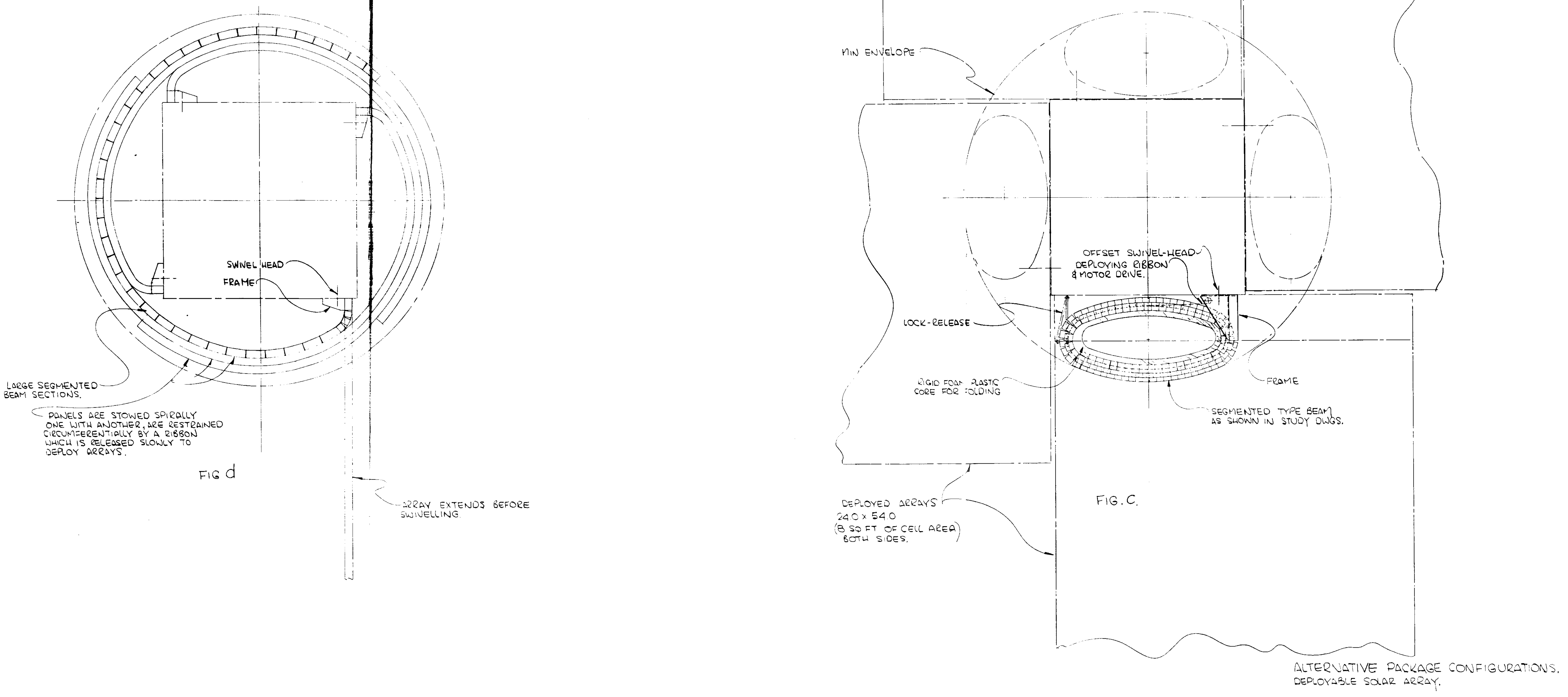


Figure 20. Alternate Solar Array Packaging Configuration

7.0 STATEMENT OF WORK AND SCHEDULE PHASE II AND PHASE III

7.1 STATEMENT OF WORK

Ryan Aeronautical Company proposes to provide the facilities, materials, and personnel to successfully complete the tasks called for under Phases II and III of NASA specifications entitled "Guidelines for research and development of deployable solar arrays" and Ryan's Proposal No. 64B057. The task to be performed is as follows:

7.1.1 Phase II - Design and Manufacture of Proof-of-Principle Unit

During Phase II, Contractor will prepare a detail design of the segmented beam configuration and release the drawings for manufacture of the proof-of-principle unit. All necessary technical analyses will be performed to support the design and assure design integrity. Thermal cycling tests will be conducted on the array substrate test panels to supplement the data obtained under Phase I. Pertinent technical data will be prepared, such as special process controls, design and quality assurance specifications.

All data would be released for the manufacture of the Proof-of-Principle unit. Aluminum chips will be used on this unit to simulate the solar cells.

To substantiate the conformance of the solar array with the design objectives, the Contractor proposes to conduct Engineering Confidence Tests using the Proof-of-Principle unit prior to the delivery of this unit to GSFC. These will consist of mechanical operational tests, and environmental tests, which are representative of the critical loading imposed on the solar array during the launch and deployment phases of the mission profile. The tests will be conducted in the following order:

Mechanical Operational Test

The solar array shall be operated in a 1 g field from the stowed to the deployed configuration a minimum of three cycles. The array shall be inspected after each cycle to insure conformance with the design requirements.

Environmental Tests

After each of the following environmental tests, the solar array will be mechanically operated and inspected:

- Vibration Resonant Survey (Stowed Configuration)

  The solar array assembly shall be attached to a fixture and fundamental mode frequencies found and noted at a low sine wave excitation level sufficient to define resonant conditions.

- Vibration-Sinusoidal (Stowed Configuration)

  The solar array assembly shall be subjected to the following excitation level-frequency combinations in the thrust axis and two orthogonal axes which are perpendicular to the axis of thrust.

Frequency	g Acceleration (0-peak)	
Octave (cps)	Thrust Axis	Orthogonal Axis
5-50	2.3	0.9
50-500	10.7	2.1
500-2000	21.0	4.2
2000-3000	54.0	17.0
3000-5000	21.0	17.0

The sweep shall be conducted once at a linear rate of 2 octaves per minute for a total up, then down time of 5 minutes.

- Vibration-High Frequency (Stowed Configuration)

  This test shall consist of White Gaussian Noise 11.5 g rms band-limited between 20 and 2000 cps for 4 minutes. The test shall be conducted in each of the following axes:

  Axis of thrust.

  Two orthogonal axes which are perpendicular to the axis of thrust.

- Acceleration-Steady State

  The solar array assembly shall be mounted on a centrifuge and spun up to a g level equivalent to that on the packaged assembly while mounted on the spacecraft. The solar array shall then be deployed under positive means while the rotational velocity is decreased until the g level at the cg of the extended solar array is equivalent to that while mounted on the spacecraft. Rates of spin-up, solar array extension and rotational de-acceleration shall be in accordance with Section 3.1. The solar array assembly shall be shielded during test from aerodynamic forces by means of a windscreen.

The Engineering Confidence Tests described herein demonstrate the critical modes of the solar array design and afford the Contractor an opportunity to assess the design for possible deficiencies and improvements and will also allow any necessary changes in the prototype units manufactured in the Phase III program.

7.1.2 Phase III - Fabrication and Delivery of Two Prototype Units

During Phase III the Contractor will manufacture two prototype solar arrays. Adequate fixturing and fabrication aids would be made to supplement those tools which were fabricated in Phase II.

Each solar array would include groups of functional solar cell modules on both sides of the substrate located in critical areas to demonstrate design integrity in the packaged, deployment sequence and fully erected positions. It is proposed that only Type II - low efficiency cells would be used. Aluminum chips will be used in areas not covered by active solar cells.

Final inspection tests will be performed on each of the prototype units prior to delivery to GSFC. These tests will be as follows:

1. Visual Inspection - Each solar array shall be visually inspected to insure conformance with the design specifications.

2. Deployment Test - Each solar array shall be operated from the stowed to the deployed configuration a minimum of three cycles to insure deployment suitability.

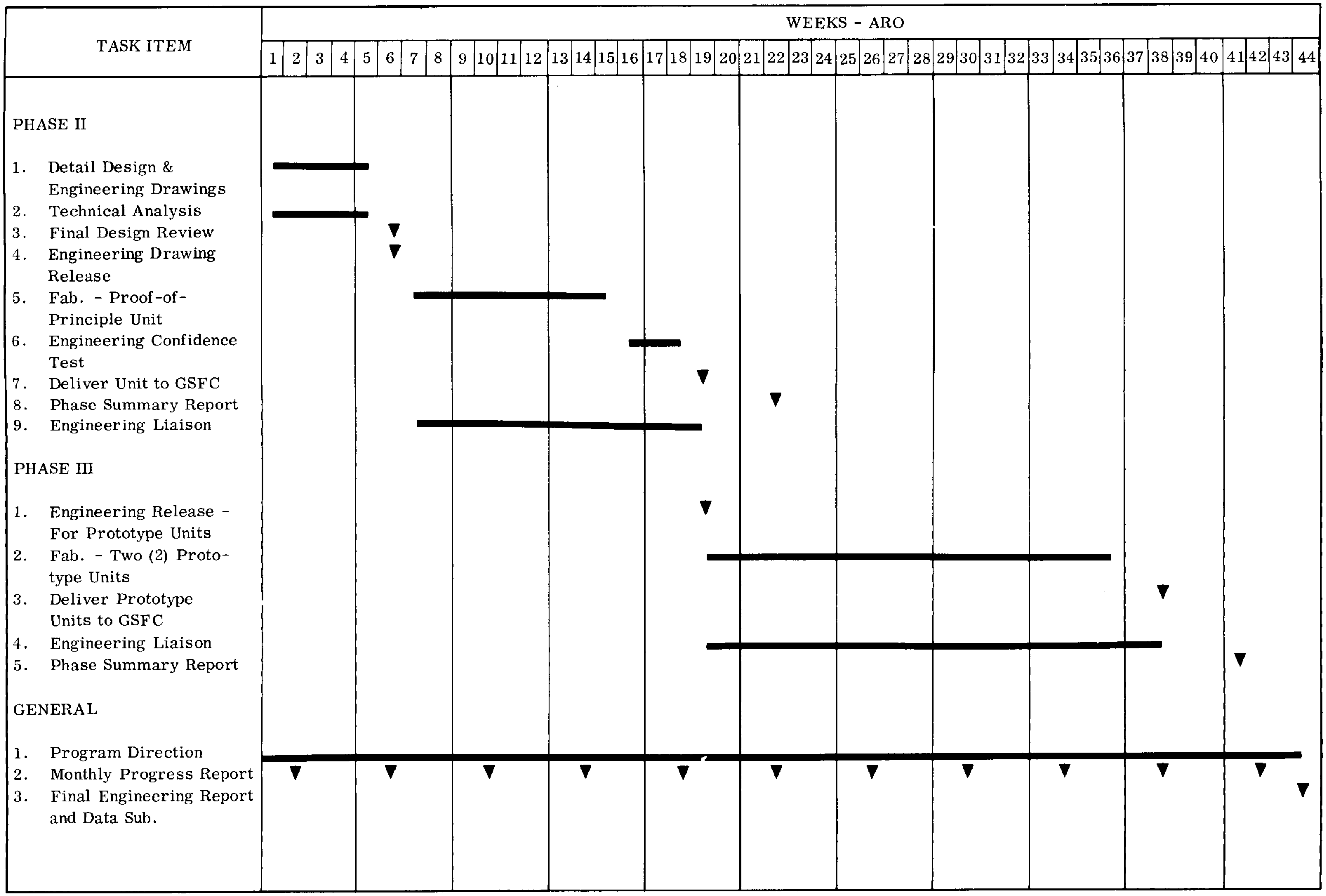
3. Electrical Test - Microscopic mechanical examination and electrical output checks shall be performed after each cycle of the deployment test.

Appropriate shipping containers, preservation and packing materials would be provided in the delivery of all assemblies.

All technical data which was generated in the program would be updated to incorporate any revisions that may have evolved and the data package submitted to GSFC at conclusion of the contract.

7.2 PROGRAM SCHEDULE

The Program Schedule on the following page shows the anticipated start and completion points for the major tasks of Phase II and Phase III of the deployable solar array development program. The schedule has been developed in accordance with the delivery requirements of GSFC Statement of Work and Ryan's Proposal 64B057.



Program Schedule